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ABSTRACT

This textbook has been prepared under the direction of the Defense Civil Preparedness Agency (DCPA) Staff College for use as a student reference manual in radiological defense (RADEF) courses. It provides much of the basic technical information necessary for a proper understanding of radiological defense and summarizes RADEF planning and expected operations. This textbook is not intended to provide RADEF operational procedures or direction for the development of RADEF plans and organizations. Such guidance will be found in other DCPA publications. Among the chapters are: (1) an Introduction; (2) Basic Concepts of Nuclear Science; (3) Effects of Nuclear Weapons; (4) Nuclear Radiation Measurements; and (5) Radiological Monitoring Operations and Techniques. (LS)

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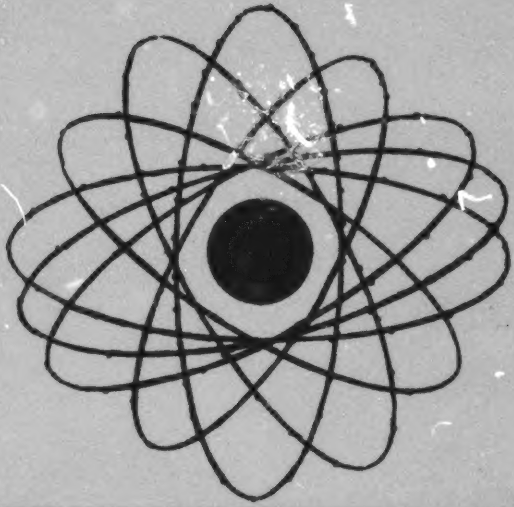
RADIOLOGICAL DEFENSE



TEXTBOOK

SE 018 843

2

DEFENSE CIVIL PREPAREDNESS AGENCY
DEPARTMENT OF DEFENSE

FOR TRAINING PURPOSES ONLY

RADIOLOGICAL DEFENSE

TEXTBOOK

DEFENSE CIVIL PREPAREDNESS AGENCY • DEPARTMENT OF DEFENSE

(Supersedes SM-11.22-2 dated JUNE 1968)

FOREWORD

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INTRODUCTION TO RADIOLOGICAL DEFENSE

A strong civil preparedness program is vital to this nation's security. Today, every citizen and officials at every level of government should be concerned with preparing for disasters of all kinds. This book is primarily concerned with one such potential disaster; that of a nuclear attack on this country.

This chapter will show why civil preparedness is vital to our security by stating the nature of the threat we face and the role that an effective preparedness posture can play in our national response to that threat. It will also define what we mean by "radiological defense" and will indicate how such defense is organized. Another objective of this chapter, and perhaps the most important one, is to explain how effective radiological defense requires trained and dedicated personnel. We cannot develop a radiological defense capability unless we can count on all of our citizens to learn something of the nature of nuclear radiation and to gain an understanding of the measures that can be taken to defend against its effects should this nation ever face nuclear attack.

THE NATURE OF THE THREAT

1.1 Any assumptions about a possible nuclear attack upon the United States are dangerous since we can never be sure about a potential enemy's objectives or even specific capabilities. Studies made by the Department of Defense and others for exercise purposes use attack patterns that represent current estimates of weapon size and total yield that could be delivered on this country in an all out nuclear attack.

1.2 Specific attack patterns assume hundreds of nuclear weapons with many millions of tons of TNT equivalent are dropped on a mixture of military, industrial and population targets as both surface and air bursts. The results vary, of course, but the unmistakable fact remains that millions of Americans would be killed outright in any such attack by the direct effects of blast and fire. The locations at which weapons were detonated would suffer unprecedented physical damage and the fallout radiation from surface weapons would affect hundreds of square miles in a downwind direction from those bursts. Additional millions of casualties would be caused depending on the amount of fallout protection available in the affected areas. In one simulated attack in which 800 nuclear weapons of 3,500 megatons were assumed, there would be about 97 million people killed either outright or who died subsequently from the direct effects or from fallout. Another 30 million would have been injured but would survive while the remaining 67 million out of a total population of 194 million would not be affected.

1.3 Three things are worth noting about this threat. They are:

First, there is no equivalent in human experience for the destructiveness of multi-megaton hydrogen weapons. It is worth remembering that all the bombing raids on Germany in World War II . . . by all the allied forces . . . together totalled but *one* megaton.

Second, not only are the weapons in a new dimension of destruction, but the delivery systems are now in a new dimension of effectiveness. Unless an anti-missile-missile is developed that can not only hit an enemy missile, but hit it almost immediately after it leaves the launching pad, and further, can discriminate between missile and decoy, the advantage in modern strategic missile warfare seems certain to remain with the attacker. This factor, coupled with the enormous destructiveness of modern weapons, places a premium on surprise.

Third, this hypothetical attack would produce casualties to more than half of our population under the conditions then prevailing. If the conditions were changed to the extent of providing an effective civil preparedness program, the casualties would be reduced to a major degree.

NOTE

Our system of ethics is based upon the belief that each individual life is precious. This belief underlies all our American institutions. It is, in fact, the basic way we differ from systems embracing totalitarianism, where the individual is the servant of the State, rather than our system where governments derive ". . . their just powers from the consent of the governed . . ." This central fact, which motivates the government in working for civil preparedness, should not be obscured by statistics dealing with millions of casualties. "Megadeath" like "genocide" are words that spring from systems of government alien to our way of life and our system of right and wrong. Unfortunately, the grim facts of the missile age force us to consider these terms, so hostile to our belief in the supreme value of the individual.

THE ROLE OF CIVIL PREPAREDNESS AND RADIOLOGICAL DEFENSE

1.4 The national defensive posture of a nation incorporates, among other things, the concept of "Active" and "Passive" offensive and/or defensive capabilities. "Active" offensive and defensive capabilities include items such as a nation's military forces and arms, both conventional and nuclear, as well as any other capability which represents an "Active" resource for implementing and maintaining an offensive or defensive posture. ICBM's, bombers, naval ships, etc., represent obvious examples of an "Active" capability. "Passive" capabilities, however, are those items lacking the visibility of a military force, but which may contribute significantly to a nation's defensive capability. Civil preparedness is a prime example of a "Passive" capability.

1.5 The Strategic Arms Limitation Talks (SALT) were designed to effect a balance of power among the two primary nuclear powers—the United States and the Soviet Union. The SALT negotiations would basically effect this balance by placing limitations or curbs upon the "Active" offensive and defensive capabilities of a nation. It then becomes apparent that, assuming the effectiveness of the SALT negotiations, a nation with a strong "Passive" defensive capability occupies a position of strength. Herein lies the importance of civil preparedness and radiological defense.

1.6 Since the civil preparedness program is a vital element of a meaningful "Passive" defensive posture, it is extremely important that it be an effective element with trained personnel ready to provide an immediate response in a crises situation. Thus, in terms of the recognizable nuclear threat, radiological defense occupies a very realistic and substantial role within the United States civil preparedness program and within the total defensive posture of the nation.

RADIOLOGICAL DEFENSE

1.7 In evaluating the results of a hypothetical nuclear attack upon the United States, several means of protection must be utilized. Assuming that a crisis period or period of marked increased international tension will probably preceed an actual attack, crisis evacuation procedures can remove segments of the population away from probable high risk areas. Additionally, to the extent that it is available, protection against blast and other direct effects should be taken by utilizing available shelters. Equally important, however, is the need in all defensive plans for protection against nuclear fallout. Radiological defense maximizes this type of protection.

1.8 Thus, radiological defense is an extremely important element of civil preparedness. Radiological defense is defined as:

The Organized Effort Through
Detection, Warning, and
Preventive and Remedial Measures
To Minimize the Effect of
Nuclear Radiation
on People and Resources.

GENERAL RADIOLOGICAL DEFENSE REQUIREMENTS

1.9 Following are the requirements of a sound radiological and civil preparedness program:

(a) A system of shelters, equipped and provisioned to protect our population from the fallout effects of a nuclear attack.

(b) Organization and planning of emergency actions necessary to restore a functioning society.

THE IMPORTANCE OF SHELTERS

1.10 Shelters—both individual and community—are "keys" for survival. This is because shelter plays a dual role in an effective radiological defense program; first, as a shield protecting individuals; and second, as a shield protecting the persons who, by possessing special knowledge, skills, and habits of organization, can combine to assure the continuing of a functioning, democratic society. Thus, a shelter is not only a passive shield; it is also an active element in the system of countermeasures that would have to be taken to assure the survival of the nation after an attack.

As radiation levels decline, people can leave their shelters to perform needed tasks of recovery. But when can they leave their shelters? This and other questions, such as determining what the radiation levels are within the shelter, can be satisfactorily answered in one way only: through accurate measurement or monitoring.

MONITORING AND THE MONITORING SYSTEM

1.11 To assure adequate measurement of radiation levels to support postattack radiological defense operations, the nation needs a large number of fallout monitoring stations. Some of these stations may be located within community shelters, since such shelters form strong points of survival and bases of ultimate recovery operations. Those community shelters that provide for extended geographic and communications coverage are particularly suited for serving in the additional capacity of monitoring stations.

1.12 Whether in separate monitoring stations or carrying out monitoring procedures from community shelters, the primary job of the monitor will be to supply information on radiation levels, information basic to survival and recovery operations. In carrying out their duties, the monitors should receive technical direction and supervision from their organizational Radiological Defense Officer.

RADIOLOGICAL DEFENSE ORGANIZATION

1.13 As stated in Public Law 85–606, it is the intent of Congress, in providing funds for radiological defense, that the responsibility for such defense be "vested jointly in the Federal Government and the several States and their political subdivisions." The division of responsibilities among governments, which is a central feature of our Federal system, is fully reflected in the organization of radiological defense. The DCPA recommended program describes in some detail the responsibility of each element and level of government, and the organization established to give effect to these levels of responsibility.

1.14 In order to make the radiological defense program a success, there is need for radiological monitoring stations at Federal, State, and local facilities throughout the nation. This means that there is a need for money to pay for the instruments and equipment required; there is need for management to assure that these stations operate effectively and in one coordinated system. But there is even more need for trained men and women who can operate the equipment, do the other specific jobs needed, and provide leadership in radiological defense matters on the local level. An essential part of such local leadership is the training of RADEF personnel.

1.15 DCPA training courses are designed to produce a core of competent radiological defense personnel including those who will go back to their communities and train others. For without trained people, the best laid plans become little more than complicated dreams. Trained men and women breathe life into plans. This is the reason behind the organization of DCPA courses. The courses offer the training. If that offering is taken—to the fullest potential—then all the effort, and planning, and hopes of those deeply concerned with protecting our society, from the President on down, will be realized. For on men and women like ourselves, in the last analysis, will lie the success of the radiological defense program.

BASIC CONCEPTS OF NUCLEAR SCIENCE

We will begin by ending the mystery. Since the aim of this book is to help you in your work of radiological defense, it is essential that you understand what you are defending against—nuclear radiation.

This, then, is the primary objective of this chapter:

Understanding Nuclear Radiation

There are many kinds of radiation, some of which, such as long and short radio waves, infrared (or heat) radiation, visible-light, and ultraviolet radiation are familiar to all of us. However, nuclear radiation, the noiseless, odorless, unseen, unfelt something that can be so deadly seems, as Winston Churchill said of Russia, "a riddle wrapped in mystery inside an enigma".

Fortunately, this need not be so. A few concentrated hours of study will quickly make radiation understandable.

However, if our job were how to stop air contamination from automobile exhausts, we would not get too far by confining ourselves to the nature of the exhaust alone. It would be necessary to study the fuel, the way the auto engine burned the fuel, as well as many other things. Only then could we understand, and possibily cope with, the factors in the exhaust fumes that were harmful.

The same need exists with nuclear radiation. If we are to understand it, we must see the whole picture; we must know the *why* as well as the *what* of nuclear radiation.

Therefore, to help us understand nuclear radiation, the major objective of this chapter, we must also have some grasp of:

WHAT is meant by "matter" and "energy"

WHAT are the kinds of nuclear radiation

WHAT is the language of nuclear physics, the terms, signs and symbols used to describe the world of the atom and radiation

WHAT is the structure of the atom

WHAT is the nature of its parts

HOW do these parts behave

HOW is nuclear radiation measured

TWO FUNDAMENTALS AND A BOMBSHELL

2.1 There are two physical laws that we must understand before we talk about the atom.

2.2 The first of these is known as the LAW OF CONSERVATION OF MATTER. According to this law, the total mass of the material universe remains always the same, regardless of all the rearrangements of its component parts. This was first demonstrated by the brilliant French physicist Antoine Lavoisier, whose genius was cut short by the French Revolution. Lavoisier burned a candle of known weight until it disappeared. He then weighed the oxygen used by the burning candle, the wax that remained and the foul gas (carbon dioxide) and water vapor formed by the burning candle. He found that the weight of the candle that disappeared and the weight of the oxygen that combined with it equalled the weight of the carbon dioxide and water vapor. This is one demonstration of the LAW OF CONSERVATION OF MATTER.

2.3 The second law of conventional physics is known as the LAW OF CONSERVATION OF ENERGY. This law states that one form of energy can be converted to another form, but the total amount of energy in the universe neither increases nor decreases.

2.4 Until 1905, matter or mass and energy were looked at as separate entities, as indeed they appear to be

2.5 Then, a young mathematician and physicist working in the Swiss Patent Office produced a bombshell. The young man was Albert Einstein. He said, in what is probably the most important mathematical equation in history, that *E equals* mc^2, or, in plain English, that there is an exact equivalence between mass and energy. Mass can be converted to energy and, even more strangely, energy can sometimes be converted to mass.

2.6 According to Einstein, it is not mass or energy as a separate entity, but rather the total mass-energy of the universe that remains constant. In his equation $E = mc^2$ E stands for energy, in ergs, generated by any reaction; m is for "mass" in grams, lost in any reaction; and c is the speed of light, equivalent to 3×10^{10} cm per second (186,000 miles per second).

NOTE

As you read through this and other chapters you may meet words and terms new or unclear to you, such as "ergs". All of these words are included in the GLOSSARY found at the end of the text.

POWER IMPLICATIONS

2.7 Although no one has succeeded through nuclear fission in converting to energy more than a small fraction of any mass, the advantages of nuclear fission over chemical power (such as combustion) are enormous. (See Figure 2.7 for some examples). For instance, in the fissioning of uranium, as in the bomb dropped over Hiroshima, only a minute part of the total mass of radioactive substance is changed to energy—but this release of energy is gigantic. The Hiroshima blast was equivalent to *20,000 tons* of TNT. This was produced by the fission of 2.2 *pounds* of uranium (since only a minute part of the total actually underwent fission, the uranium contained in the bomb was considerably more than 2.2 pounds). Why so little mass can produce so much energy is precisely what was explained in Einstein's $E = mc^2$ formula.

NATURE OF MATTER

2.8 About the year 1900 a chemist, if asked to explain the material world in

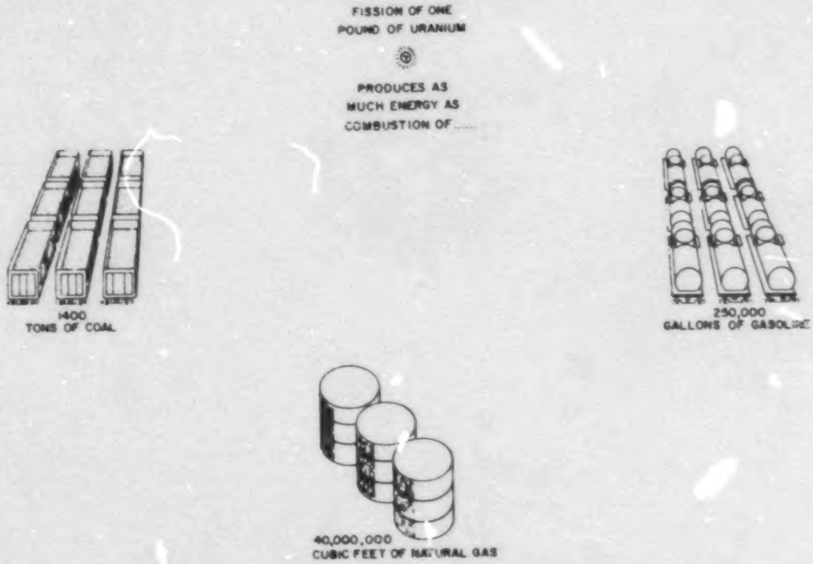


FIGURE 2.7.—Nuclear energy as compared with chemical energy

FIGURE 2.7—Nuclear energy as compared with chemical energy.

non-technical language, would have spoken somewhat as follows, stressing certain facts that are *still valid* and are *still fundamental* to an understanding of more recent discoveries.

2.9 The chemist would speak of ELEMENTS, of the ATOM, of MIXTURES and COMPOUNDS, of ATOMIC WEIGHT and the PERIODIC TABLE. Let us take these one at a time

2.10 *Elements.*—All material is made up of one or more elements. These are substances that cannot be broken down into other and simpler substances by any chemical means. Our 1900 vintage chemist did not know it, but you will see later, that it is possible to cause both decomposition and production of certain elements by means of nuclear reactions. There are now over 100 known basic materials or elements such as iron, mercury, hydrogen, etc., that have been discovered and classified. Some have never been found in a natural environment, but are manmade.

2.11 Iron, mercury, and hydrogen—existing at normal temperatures as a solid, a liquid, and a gas respectively—are typical elements. By heating, a solid element can be changed to a liquid and even to a gas. Conversely, by cooling, a gaseous element can be changed to a liquid and even to a solid.

2.12 *The Atom.*—The smallest portion of any element that shares the general characteristics of that element is called an ATOM, which is a Greek word meaning INDIVISIBLE PARTICLE.

2.13 *Mixtures.*—Elements may be mixed without necessarily undergoing any chemical change. For example, if finely powdered iron and sulfur are stirred and shaken together, the result is a mixture. Even if it were possible to grind this mixture to atom-size particles, the iron atoms and the sulfur atoms would remain distinct from each other.

2.14 *Compounds.*—Under certain conditions, however, two or more elements can be brought together in such a way that they unite chemically to form a compound. The resulting substance may differ widely from any of its component elements. For example, drinking water is formed by the chemical union of two gases, hydrogen and oxygen; edible table salt is *compounded* from a deadly gas, chlorine, and a poisonous metal, sodium.

2.15 Whenever a compound is produced, two or more atoms of the combining elements join chemically to form the MOLECULE that is typical of the compound. The molecule is the smallest unit that shares the distinguishing characteristic of a compound.

2.16 *Atomic Weight.*—Hydrogen is the lightest element. Experiments have demonstrated that the oxygen atom is almost exactly 16 times as heavy as the hydrogen atom. Chemists express this truth by saying that oxygen has an ATOMIC WEIGHT of 16. Through many experiments, the atomic weights of the remaining elements have been found.

2.17 *The Periodic Table.*—Figure 2.17 is a standard table of the elements. The atomic number of each element appears above its chemical symbol. The vertical columns represent family groups. All members—from the lightest to heaviest—of a family behave like one another in forming (or refusing to form) chemical compounds with other families.

2.18 While still essentially correct, this circa 1900 chemist's view of matter needs to be supplemented (but not entirely replaced) by an analysis of the atom. In 1900, only a few advanced scientists had become convinced that the atom is *divisible* after all. This was a new idea, since the atom is very small, having an overall diameter of about 10^{-8} centimeters.

THE ATOM AND ITS BUILDING BLOCKS

2.19 Small as it is, the atom proved to be composed of yet smaller particles. In fact, as shown in Figure 2.19a, it proved to be mostly empty space, with the actual matter contained in a central mass. The new knowledge of the nature of the atom has added many terms to those known to our 1900 vintage chemist. Let us take a few of these terms and relate them to some diagrams of the atom. The terms most useful are NUCLEUS, ELEC-

THE PERIODIC TABLE OF THE ELEMENTS

	Groups																	
	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIII			IB	IIB	IIIB	IVB	VB	VIB	VIIB	0
Period 1	1 H																	2 He
Period 2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
Period 3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
Period 4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
Period 5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 (Tc)	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
Period 6	55 Cs	56 Ba	57–71 Lantha-nides	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
Period 7	87 Fr	88 Ra	89–10 Acti-nides	104 (–)														

Lanthanide Series	57 La	58 Ce	59 Pr	60 Nd	61 (Pm)	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinide Series	89 Ac	90 Th	91 Pa	92 U	93 (Np)	94 (Pu)	95 (Am)	96 (Cm)	97 (Bk)	98 (Cf)	99 (Es)	100 (Fm)	101 (Md)	102 (–)	103 (Lw)

Figure 2.17

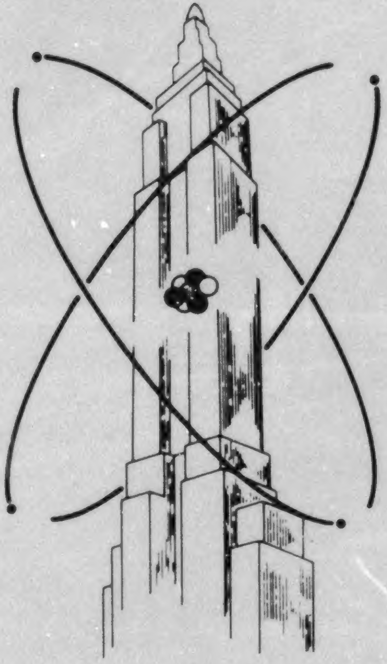


FIGURE 2.19a.—If an atom were the size of the Empire State Building, its nucleus would be as large as a pea and the electrons would revolve around the nucleus at a distance of several hundred feet. (Understanding that there is so much unoccupied space within the atom is important to an understanding of the interaction of radiation with matter.)

TRONS, PROTONS and NEUTRONS, the latter three comprising the basic atomic building blocks as shown in detail in Figure 2.19b.

2.20 The NUCLEUS is the heavy, dense core of the atom, containing practically all of its weight. As we have seen, this nucleus is surrounded at quite some distance by ELECTRONS which whirl around the nucleus at tremendous speeds. Electrons are very small and have practically no weight.

UNIT	SYMBOLS	WEIGHT OR RELATIVE MASS IN ATOMIC MASS UNITS *	RELATIVE ELECTRICAL CHARGE
PROTON	p OR [illegible]	1.007593 amu *	+1
NEUTRON	n OR $_0n^1$	1.00898 amu	0
ELECTRON	e OR e^- OR $_{-1}e^0$ OR -	0.000549 amu	-1

* AN ATOMIC MASS UNIT (amu) IS EQUAL TO 1.6×10^{-24} GRAMS OR ONE BILLIONTH OF A BILLIONTH OF A MILLIONTH OF A GRAM

FIGURE 2.19b.—Atomic building blocks.

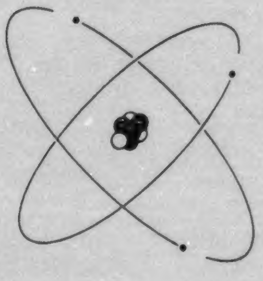


FIGURE 2.21.—Elementary particles that make up an atom.

2.21 If we examine the structure of the nucleus in greater detail, we see that it consists of little individual balls of matter that are about the same size in all atoms. Some of these little balls of matter have a *positive electrical charge*. These are called PROTONS. Others, called NEUTRONS, have *no* electrical charge and are said to be electrically neutral. Both a proton and a neutron are much larger and heavier than an electron (see Figure 2.21).

2.22 For each positively charged PROTON in the nucleus, there is a negatively charged electron in orbit around the nucleus. The number of protons in the nu-

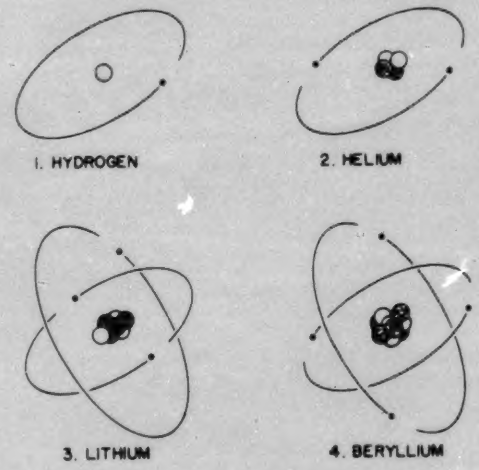


FIGURE 2.22—Comparing the atoms of the first four elements.

cleus, therefore, determines the number of electrons which are in orbit around the nucleus. *The number of protons also determines the nature of the element.* For example, the single positive charge on the hydrogen nucleus balances the negative charge on the electron. Thus, in its normal or UNEXCITED state, the hydrogen atom as a whole is electrically neutral. The next element heavier than hydrogen is helium, and it has two electrons that move in a single orbit. Two positive charges in the helium nucleus counterbalance the negative effect of the two electrons. Lithium, the next heavier element, has three electrons. Only two of these travel in the comparatively small area near the nucleus, the third has a much larger orbit. The lithium nucleus, therefore, has three positive charges. See Figure 2.22 for examples.

2.23 If time and space permitted, the atoms of all the elements could be examined one by one. For present purposes, however, the oxygen atom (Figure 2.23) will be an adequate example.

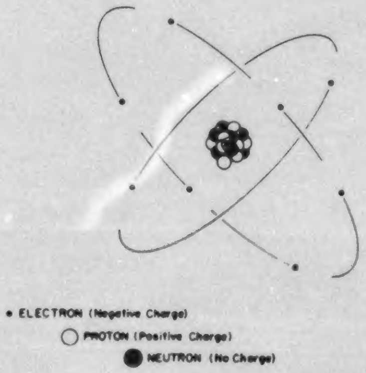


FIGURE 2.23.—The oxygen atom.

2.24 The oxygen atom has eight protons, and therefore eight positive charges in its nucleus. To balance these eight positive charges, eight electrons are required. The first two electrons are in the inner orbit, as is normal in any atom above hydrogen. Three outer orbits, contain the other three pairs of electrons, as shown in the drawing. One way to think of the six outer electrons, all revolving and spinning, is as if they were tracing a hollow shell like an ultra-light tennis ball. Scientists customarily speak of electrons as being located in SHELLS, classified as K, L, M, N, O, P, A, and sub-shells, in accordance with their energy level, which is proportional to a distance from the nucleus.

2.25 Continuing with our detailed look at the oxygen atom, we see that in addition to the eight protons and the two shells with a total of eight eleltrons, there are also eight uncharged particles or neutrons.

2.26 With the single exception of hydrogen in its simplest form, all atomic nuclei contain neutrons as well as protons. The lighter elements tend to have approxi-

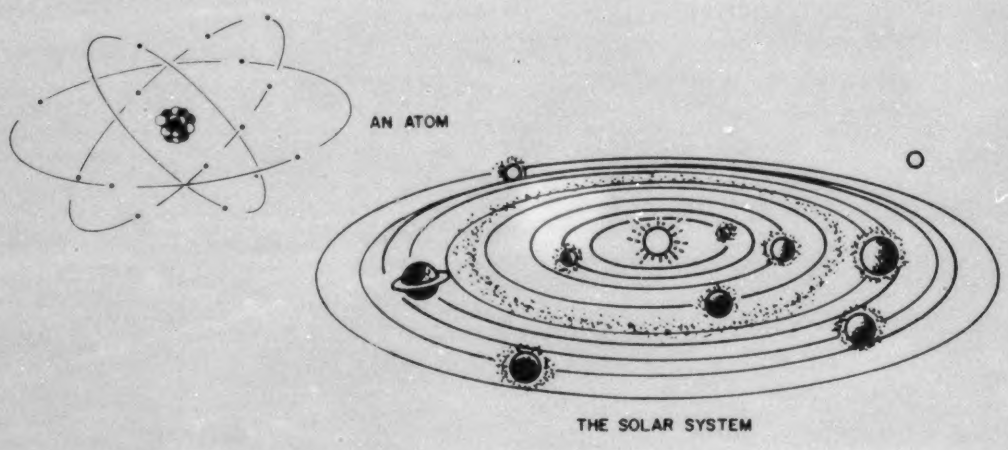


FIGURE 2.24.—Another way of viewing the atom is as a minute solar system. Instead of the sun at the center, there is the nucleus; instead of the planets in orbit, there are the electrons.

mately equal quotas of neutrons and protons; *the heavier elements have more neutrons than protons.* This fact, to be explained in greater detail later, is important to an understanding of radiation.

ISOTOPES

2.27 The number of neutrons in the nucleus may range from zero to almost 150. In certain elements it is found that different atoms of the same element have the same number of protons but vary in the number of neutrons. To the chemist, this is of little concern because the chemist works with the orbital electrons, and since all of these atoms have the same number of protons, they will have the same number of electrons in orbit. Since they have a different number of neutrons in the nucleus, however, the various atoms of the same element will not all weigh the same.

MASS.—A measure of the quantity of matter

WEIGHT.—A measure of the force with which matter is attracted to the earth

2.28 To the nuclear physicist and physical chemist, these are different forms of the same chemical element differing only in the number of neutrons in the nucleus. Many of the isotopes are stable. Some of the isotopes are unstable, *and therefore radioactive.*

2.29 Figure 2.29 shows various isotopes of the element hydrogen. The heavier isotopes make up a very small fraction of one percent of the total amount of hydrogen found in nature. Ordinary water consists of molecules each of which is made up of two atoms of hydrogen and one atom of oxygen. If water contains hydrogen which is *not* the *normal isotope* of hydrogen (one proton) but the deuterium isotope (one proton and one neutron) it will look like regular water, taste like regular water, and, from the chemical point of view, it will be water. However, from a nuclear point of view, this is HEAVY WATER because it is made with the heavier isotope of hydrogen.

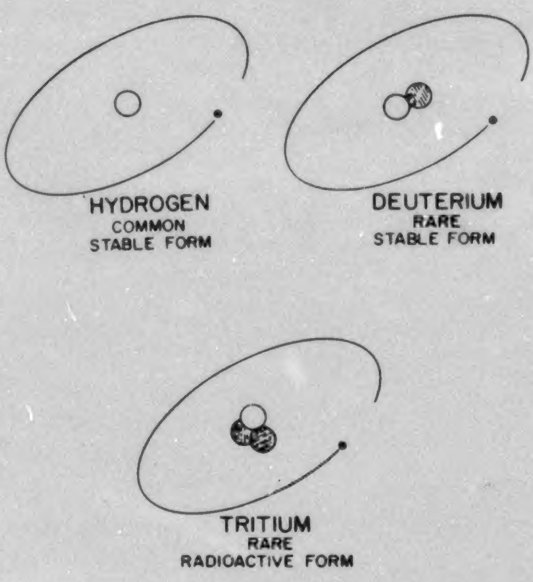


FIGURE 2.29.—Isotopes of the element hydrogen.

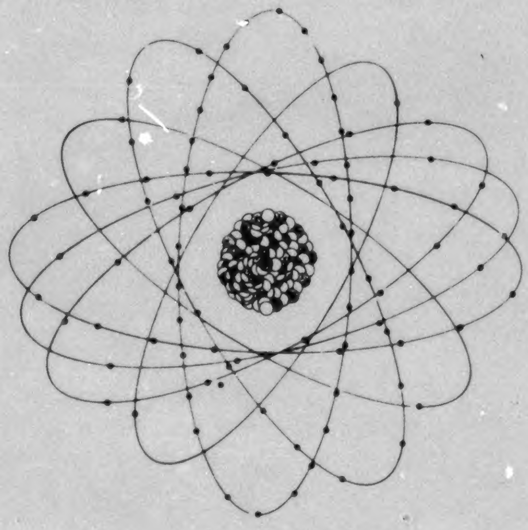
2.30 The third form of hydrogen called tritium contains one proton and two neutrons in its nucleus. The addition of the second neutron to the nucleus produces an unbalance in the proton to neutron ratio thereby causing an unstable or *excited* condition due to the excess energy. This excess energy is emitted in the form of *radiation.* Tritium is the only isotope of hydrogen that is radioactive.

2.31 Only three isotopes of the element hydrogen exist. Attempts to produce a fourth isotope fail because the nucleus of a tritium atom will not capture an additional neutron.

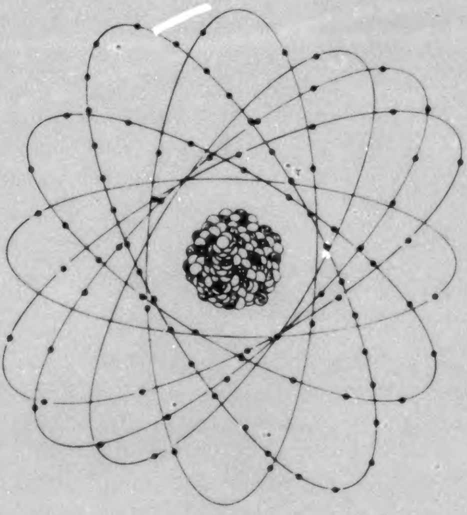
2.32 Figure 2.32 shows two different isotopes of uranium. One is called uranium 238. Its nucleus contains 92 protons and 146 neutrons which combined total 238 particles. The other, uranium 235, contains 92 protons and 143 neutrons which total 235 particles. Both of these will react chemically in exactly the same way. Therefore, to the chemist they are the same. The important difference to the nuclear physicist is the fact that, although both are radioactive, the U^{235} will sustain a chain reaction whereas the U^{238} will not.

2.33 As previously stated, the first element, hydrogen, has only three isotopes in its family. The number of isotopes for each of the other elements varies considerably with, for example, as many as 25 istotopes for the fiftieth element, tin.

2.34 Altogether there are over 1,200 isotopes, the majority of which are radioactive. Most elements have two or more isotopes. While the number of neutrons in the nucleus does not materially affect chemical behavior, the neutron to proton (n:p) ratio of the nucleus does affect the atom in other ways.



URANIUM^{235}
RADIOACTIVE



URANIUM^{238}
RADIOACTIVE

FIGURE 2.32.—Isotopes of the element uranium.

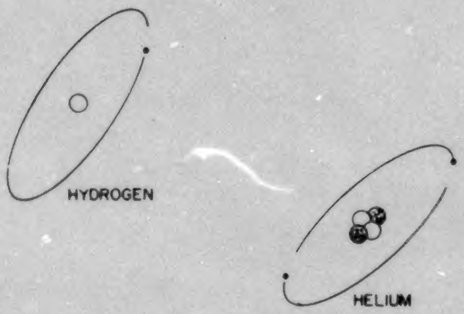


FIGURE 2.39a.--Atoms of the element hydrogen and the element helium.

We are close to our main objective—
—understanding nuclear radiation!!!

2.35 Before the discovery of the neutron, scientists identified any element by a one-letter or two-letter symbol representing its chemical name—H for hydrogen, Cl for chlorine, Na for sodium (whose latinized technical name is natrium, hence the Na), and so on. The nuclear physicist accepts these time-honored letter symbols; but when speaking in general terms, he refers to any of them as SYMBOL X.

2.36 To make precise reference to a given atom, the nuclear physicist (1) precedes symbol X with a numerical *subscript* called SYMBOL Z and (2) follows symbol X with a number (often, but not always, written as a *superscript*) called SYMBOL A. His identification of an atom, then, takes the form $_{Z}X^{A}$ or sometimes when Z is clearly understood, simply X^{A} or XA. For example, U235 and U238.

2.37 *SYMBOL Z.*—The subscript Z is called the ATOMIC NUMBER; it tells how many protons the nucleus contains (and simultaneously, of course how many planetary electrons the atom has in its normal state). For hydrogen Z is 1; for oxygen it is 8; for uranium it is 92.

2.38 *SYMBOL A.*—The final identifying symbol is an ATOMIC MASS NUMBER representing the sum of the protons and the neutrons.

SUBSTANCE SYMBOL	PROTONS (Z)	ATOMIC MASS NUMBER (A)	NEUTRONS (A-Z)	ELECTRONS (=Z)
HYDROGEN $_1H^1$	1	1	0	1
DEUTERIUM $_1H^2$ OR $_1D^2$	1	2	1	1
TRITIUM $_1H^3$ OR $_1T^3$	1	3	2	1
OXYGEN $_8O^{16}$	8	16	8	8
URANIUM $_{92}U^{238}$	92	238	146	92

FIGURE 2.39b.—Symbol meanings.

IMPORTANT

To find the number of *neutrons* in any fully identified atom, subtract Z from A.

2.39 Let us see a few examples of the uses of these symbols. In Figure 2.39a, we see an atom of hydrogen with the subscript 1 as its atomic number (Z), since hydrogen has only one proton, and superscript 1 as its atomic mass number (A), since the atom contains only the one proton and no neutrons. The Z number for helium is two, since it has two protons in the nucleus. As we have seen, each element has a distinctive atomic number representing the number of protons in the nucleus, and we can determine the number of neutrons in the nucleus by subtracting the atomic number Z from the atomic mass number A. As examples, the nucleus of $_{92}U^{238}$ contains 146 neutrons and the nucleus of $_{27}C^{59}$ contains 32 neutrons. Since normal atoms are electrically neutral, each atom will have the same number of electrons as there are protons in the nucleus, i.e., the Z number will equal the number of protons in the nucleus or the number of electrons in orbit about the nucleus. The subscript Z number is sometimes disregarded because the atom is identified by chemical symbol. Thus He^4 or $_2He^4$ both have the same meaning. Figure 2.39b shows how symbols are interpreted.

2.40 The ratio of neutrons to protons within the nucleus of the atom largely determines the stability of the atom. The protons being positively charged tend to repel each other. The repulsive force is counteracted, however, by a nuclear attractive force called *Binding Energy*. Very little is known of this energy. However, it is known that for elements which have relatively low atomic weights, nuclear stability occurs when the number of protons and neutrons are nearly equal. Heavier elements, those with higher Z numbers, require a higher neutron to proton (n:p) ratio for stability. Whereas those elements in the lower part of the periodic table (Figure 2.17) are stable when the isotope has an n:p ratio of approximately one (approximately the same number of neutrons as protons). The n:p ratio must increase as the Z number increases if the stability of the atom is to be maintained. Beginning with the element bismuth, atomic number 83, when the n:p ratio increases above 1.5:1 there are no stable isotopes. The stable range of n:p ratios for many elements is not critical, i.e., there are several elements with many stable isotopes.

2.41 An *unstable atom*, one with a n:p ratio either too high or too low, will eventually achieve stability by spontaneous emission of energy and/or particles from its nucleus. This process is known as RADIOACTIVITY. It may be the natural decay of unstable isotopes which occur in nature or it may be as the result of artificial radioactivity which has been caused by man. In each case the nucleus is in an unstable or excited state, having an *excess of energy which will be radiated allowing the nucleus to achieve a stable or ground state.*

RADIOACTIVITY is the spontaneous disintegration of unstable nuclei with the resulting emission of *nuclear radiation.*

2.42 Radiation is the conveyance of energy through space. Everyone is familiar with the radiation of heat from stoves, light from electric lights and the sun, and the fact that some kind of energy is received by our radio and television sets to make them operate. The radiation of energy from radioactive materials is compa-

ANGSTROM UNIT - A PHYSICAL UNIT OF LENGTH, EQUAL TO 1/10^8 CENTIMETERS.

ELECTRON VOLT - THE AMOUNT OF ENERGY ACQUIRED BY AN ELECTRON FALLING THROUGH A POTENTIAL DIFFERENCE OF ONE VOLT.

ELECTRON VOLTAGE (V) IS RELATED TO THE WAVELENGTH OF RADIATION (λ), IN ANGSTROM UNITS, APPROXIMATELY THUS $V = 12420/\lambda$

WAVELENGTH AND FREQUENCY ARE RELATED BY: $c = \lambda \nu$

c = VELOCITY OF ELECTROMAGNETIC WAVES = 3×10^{10} CENTIMETERS PER SECOND

ν - FREQUENCY = CYCLES/SEC. = VIBRATIONS PER SECOND

λ = WAVELENGTH IN CENTIMETERS

VISIBLE SPECTRUM LIMITS
4,000 ANGSTROMS - 8,000 ANGSTROMS
7.5×10^{14} CYCLES/SEC. 3.7×10^{14} CYCLES/SEC.

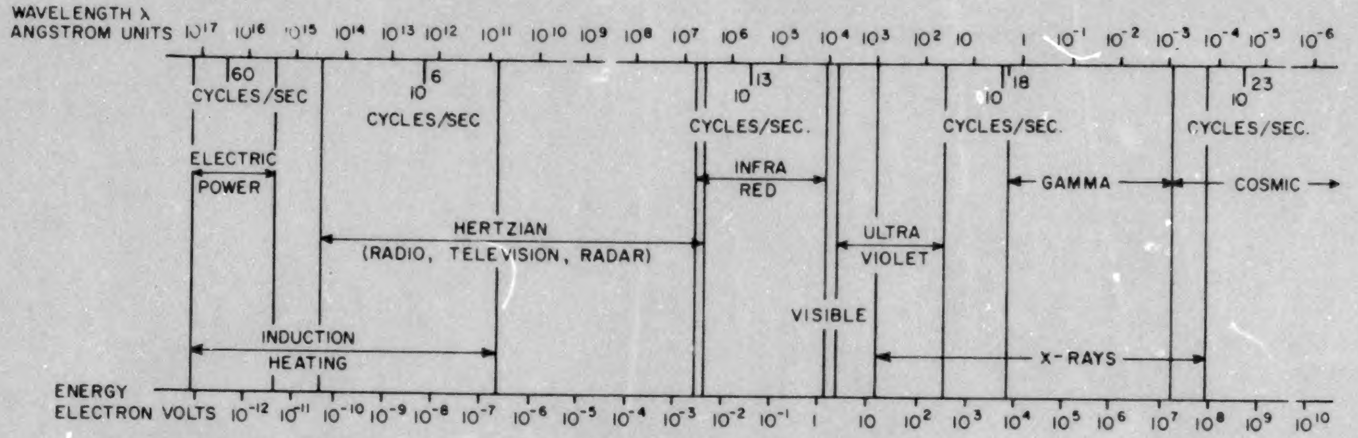

WAVELENGTH λ
ANGSTROM UNITS
10¹⁷ 10¹⁶ 10¹⁵ 10¹⁴ 10¹³ 10¹² 10¹¹ 10¹⁰ 10⁹ 10⁸ 10⁷ 10⁶ 10⁵ 10⁴ 10³ 10² 10 1 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶
60 CYCLES/SEC
10⁶ CYCLES/SEC
10¹³ CYCLES/SEC.
10¹⁸ CYCLES/SEC.
10²³ CYCLES/SEC.
ELECTRIC POWER
INFRA RED
GAMMA
COSMIC
HERTZIAN (RADIO, TELEVISION, RADAR)
ULTRA VIOLET
VISIBLE
INDUCTION HEATING
X-RAYS
ENERGY
ELECTRON VOLTS
10⁻¹² 10⁻¹¹ 10⁻¹⁰ 10⁻⁹ 10⁻⁸ 10⁻⁷ 10⁻⁶ 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 1 10 10² 10³ 10⁴ 10⁵ 10⁶ 10⁷ 10⁸ 10⁹ 10¹⁰

FIGURE 2.42.—Electromagnetic spectrum.

rable to these familiar forms of radiation but, as indicated by Figure 2.42, are generally higher in frequency and, therefore, represent greater energies.

NOTE

Remember, radioactivity is a PROCESS. Nuclear radiation is the PRODUCT of this process.

2.43 Atoms in the unbalanced state described in paragraph 2.41 are said to be RADIOACTIVE. They are spontaneously emitting some type of IONIZING radiation energy. IONIZATION is a process which results in the formation of electrically charged particles (IONS) from neutral atoms or molecules.

2.44 For a closer look at ionization, consider Figure 2.44 in which a normal atom is subjected to a bombardment of energy. The energy of this bombardment may knock an electron from its orbit into free space, i.e., it will not be associated with any atom. It is a negatively charged particle in space and is referred to as a NEGATIVE ION. The remainder of the atom from which the electron was dislodged is also electrically unbalanced by this event. Having lost one electron with its negative charge, it now has an effective net positive charge of one since it now contains one proton for which there is no counterbalancing electron. The positively charged atom (or atoms) is known as a POSITIVE ION. The two particles, the positive ion (atom or atoms) and the negative ion (dislodged electron) are known as an ION PAIR. The process which caused this separation of particles making up the atom and the attendant electrical unbalance is known as IONIZATION.

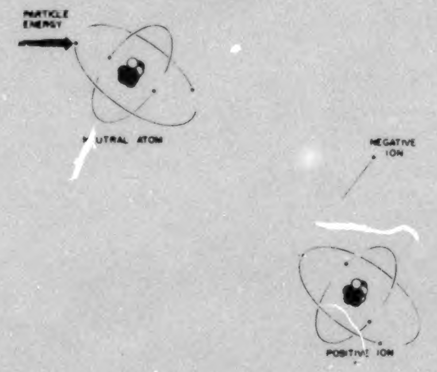
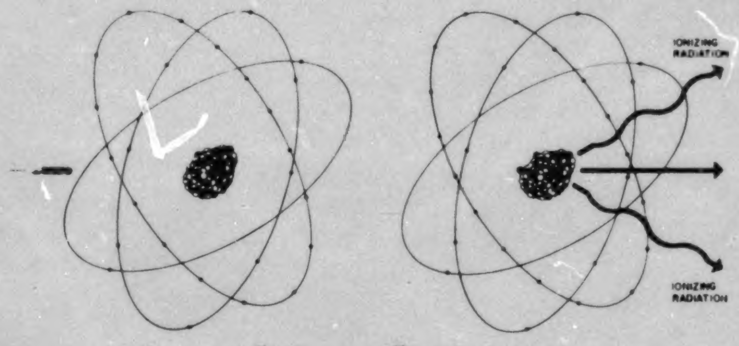


FIGURE 2.44.—Ionization.

2.45 Nuclear radiations are given off by atoms which have more than the normal complement of energy. The physicist says they are UNSTABLE. This unstable condition is often caused by too low or too high an n:p ratio as explained earlier. Radioactive atoms literally erupt from time to time emitting energy from the nucleus. These nuclear radiation emissions are classified as ALPHA PARTICLES, BETA PARTICLES and GAMMA RAYS. Each type of radiation will be discussed in more detail in later paragraphs.



$({}_{27}\mathrm{Co}^{59} + {}_{0}n^{1} \longrightarrow {}_{27}\mathrm{Co}^{60} + \text{IONIZING RADIATION})$

FIGURE 2.47.—The normal atom of Co^{59} bombarded by a neutron. In this case, the atom accepts this neutron in its nucleus, the A number increases by one to Co^{60} and the atom is radioactive.

2.46 Nuclear radiation differs from other forms of radiation in the sense that the nucleus of an unstable atom contains an excess of energy which will be emitted regardless of man's efforts. Use of heat, chemicals or pressure will not stop or alter the rate of nuclear radiation emissions from a radioactive atom. Man can cause or stop other types of radiation such as heat, light, or even other atomic radiations which in many ways compare to nuclear radiation. In the case of heat and light radiations caused by electricity, merely flipping a switch can start or stop these radiations.

2.47 Many nuclear radiations are caused by bombarding atoms with energy, causing them to radiate energy which ceases whenever the bombardment stops. However, if the atoms in the material become radioactive as a result of the bombardment, they will then spontaneously emit ionizing radiation of one or more types until they reach a stable condition. One of the sources of nuclear radiation commonly encountered in radiological defense training is ${}_{27}Co^{60}$ (Cobalt 60). Figure 2.47 shows how this isotope of Cobalt is developed from ${}_{27}Co^{59}$.

2.48 Different radioactive elements vary greatly in the frequency with which their atoms erupt. Some radioactive materials in which there are only infrequent emissions or radiations tend to have a very long life while those which are very active, radiating frequently, may have a comparatively short life. The time difference is very great between short and long lived radioactive materials. Some substances may stabilize themselves in a small part of a second, while a radioactive isotope with a long life may change or decay only slightly in thousands or millions of years. The rate of radioactive decay is usually measured in HALF-LIFE, the time required for the radioactivity of a given amount of a particular material to decrease to half its original value.

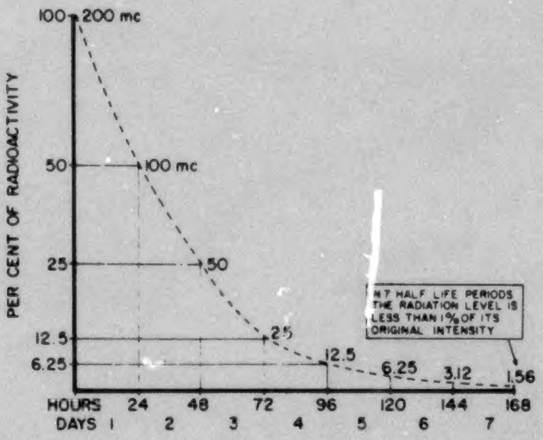


FIGURE 2.49.—Decay curve.

2.49 The half-life of a radioactive material may range from fractions of a second up to millions of years. The following radioactive elements demonstrate this wide range of half-lives: argon 41,109 minutes; iodine 131, 8 days; radium 226, 1,620 years; plutonium 239, 24,000 years. Figure 2.49 depicts a gamma emitting material with a 24-hour half-life. This material when first made radioactive has a quantity of radioactivity of 200 millicuries. In 24 hours the radioactivity would be down to 100 millicuries; in another 24 hours it would be down to 50; in another 24 hours it would be down to 25, etc.

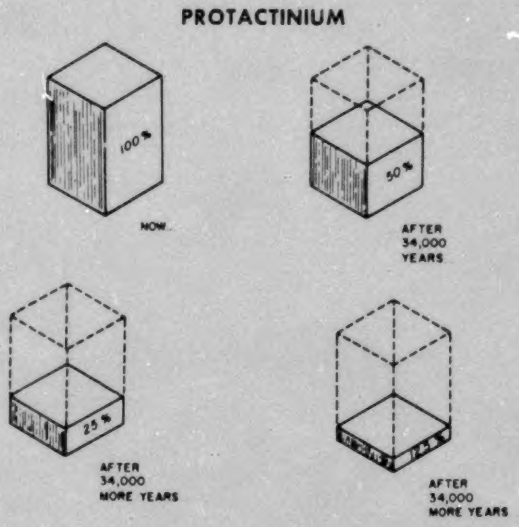


FIGURE 2.50.—Another view of half-life.

2.50 Let us look at another example. Assume that the block shown at the upper left in Figure 2.50 is composed entirely of the radioactive protactinium isotope known as Pa^{231}. The half-life of this particular isotope is 34,000 years. At the end of 34,000 years, therefore, half of the original protactinium atoms will have undergone transmutation to other elements. The rest will still be protactinium. If they were separated from the transmuted atoms, the protactinium atoms would now constitute the second block in Figure 2.50.

2.51 The second block will not decay completely in the second 34,000 year period. Unquestionably, it has only half as many atoms as the original block; but by that very fact it offers only half the original opportunity for atomic reactions to take place. As before, half of the atoms (a quarter of the original protactinium atoms) will remain unchanged at the end of the second half-life.

2.52 During the third half-life, the number of protactinium atoms will again be cut in half—and so on. In general terms, then "x" grams of any radioactive isotope will decay in accordance with the following series:

$$\frac{x}{2}+\frac{x}{4}+\frac{x}{8}+\frac{x}{16}+\frac{x}{32}+\frac{x}{64}+\frac{x}{128}+\frac{x}{256}\cdots\cdots+\frac{x}{n}$$

2.53 No matter how far this series is extended, its final term, x/n will represent only half of the protactinium atoms that were intact at the beginning of the given half-life. If x/n atoms have been lost during the preceding half-life through decay, an equal number still remain to start the next half-life.

2.54 In other words, the sum of this series *approaches* x, the original number of atoms, but (in theory at least) never quite reaches it. There is always a fraction, equal to x/n, representing the atoms that are still intact.

2.55 A useful rule of thumb is that the passage of 7 half-lives will reduce the radioactivity to a little less than 1 percent of its original activity, and in 10 half-lives the activity will be down to less than 0.1 percent. The shorter the half-life, the more highly radioactive the material will be.

2.56 As we will see in more detail in subsequent chapters, half-life has important bearings on safety. It is obvious, first of all, that any isotope with a long half-life is potentially dangerous if it is produced in large amounts. When such an isotope is once formed—whether by nature or in an atomic power plant or during a nuclear explosion—it will contaminate its surroundings for a long time to come.

2.57 For some of the artificially produced radioactive isotopes, the half-life is measured in hours, minutes, or even seconds. These isotopes are extremely active; that is why they decay so fast.

COMMON TYPES OF NUCLEAR RADIATION

2.58 There are three common types of nuclear radiation with which you must become familiar: ALPHA and BETA PARTICLES, and GAMMA RAYS.

2.59 *Alpha Radiations* emitted by radioactive materials are often called alpha radiation or simply alpha. Alpha particles are comparatively large, heavy particles of matter which have been ejected from the nucleus of a radioactive material with very high velocity. The velocity with which these particles leave the nucleus determines the distance (range) that they will travel in any substance. As indicated in Figure 2.59, an alpha particle carries a net positive electrical charge of two and an atomic mass of 4.00277. Thus the alpha particle is equal to the nucleus of a helium atom which contains two protons (with one positive charge each) and two neutrons. However, when we compare the speed of alpha to that of beta and gamma, we find this to be a relatively slow rate as might be expected due to alpha's size and weight. Alpha rays are literally small pieces of matter traveling through space at speeds of 2,000 to 20,000 miles per second. When a radioactive atom decays by emitting an alpha particle, transmutation of this atom to an atom of lower atomic number (Z) and lower atomic mass number (A) occurs.

RADIATION SYMBOLS	TYPE	ATOMIC MASS UNITS	ELECTRICAL CHARGE	REMARKS
ALPHA α	PARTICLE	4.00277	+2	IDENTICAL TO A HELIUM ATOM STRIPPED OF ITS ELECTRONS
BETA β	PARTICLE	0.000549	−1	IDENTICAL TO A HIGH-SPEED ELECTRON
GAMMA γ	ENERGY	NONE	NONE	ELECTROMAGNETIC WAVE OF ENERGY

FIGURE 2.59.—Characteristics of nuclear radiation.

2.60 *Beta Particles* are identical to highspeed electrons. They carry a negative electrical charge of one and are extremely light, traveling at speeds nearly equal to the speed of light, 186,000 miles per second. Although the atomic nucleus does not contain free electrons, only protons and neutrons, the electrons which are emitted as beta particles result from the spontaneous conversion of a neutron into a proton and an electron. The neutron which lost or emitted the beta particle has become a proton with a positive charge and thus the atom has been changed. Transmutation has produced an atom with a higher Z number.

2.61 *Gamma Rays* are a type of electromagnetic radiation which travel with the speed of light. As indicated in Figure 2.59, they have no measurable mass or electrical charge. We have become accustomed to the use of X-rays in the medical field. X-rays and gamma rays are similar, but there are two important differences between them. First, as indicated in Figure 2.42, while there is some overlapping, gamma rays are generally of a higher frequency. The basic difference, however, is their source. *Gamma rays originate in the nucleus while X-rays originate in the cloud of electrons about the nucleus.* The emission of an alpha or beta particle from the nucleus of an atom as shown in Figure 2.61, almost invariably leaves the nucleus with an excess of energy (excited state) and will be accompanied by the emission of gamma rays to reach ground or stable condition.

2.62 The neutron is another type of radiation which accompanies certain types of nuclear reactions but is not encountered in natural radioactive decay. As was discussed previously, this type radiation is

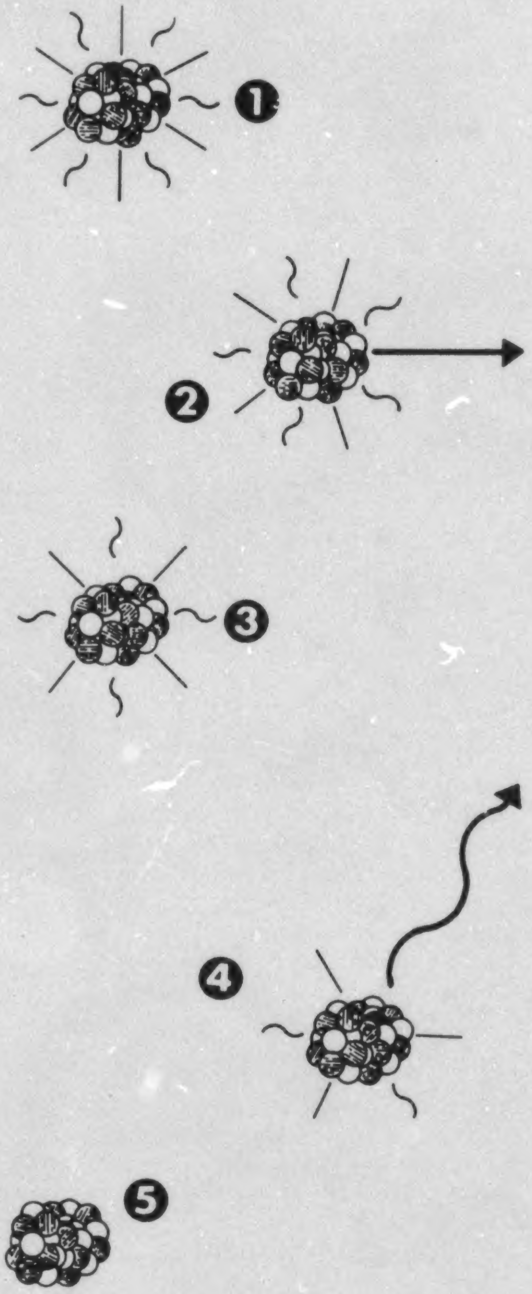


FIGURE 2.61.—Excited to stable nucleus.

able to induce radioactivity in stable isotopes.

RADIOACTIVE DECAY AND DAUGHTER PRODUCTS

2.63 Radioactive decay, often results in "transmutations", i.e., the change of one element into another and the dream of the medieval alchemists. Some radioisotopes decay directly to a stable state in one transmutation. Others decay through a series of transmutations or steps forming different radioactive elements called DAUGHTER PRODUCTS before finally reaching a stable state.

2.64 Consider now what happens when a radioactive isotope emits radiation, and follow one atom of uranium through its successive transmutations. Starting with an atom of uranium 238, which has 92 protons and 146 neutrons, follow the transmutations in Figure 2.64.

2.65a Uranium 238 emits an alpha particle. An alpha particle consists of two protons and two neutrons, and therefore is an atomic nucleus in its own right. It is the nucleus of the helium atom. (Helium has a nucleus composed of two protons and two neutrons.) With the alpha particle emitted, there are now 90 protons and 144 neutrons. The nucleus now weighs 234 units; and since the number of protons has been changed, *it is no longer uranium but is, in fact, thorium 234.*

ELEMENT AND ATOMIC WEIGHT	TYPE OF RADIATION EMITTED	NUMBER OF	
		PROTONS	NEUTRONS
URANIUM-238	ALPHA PARTICLE	92 -2	146 -2
THORIUM-234	BETA PARTICLE	90 +1	144 -1
PROTACTINIUM-234	BETA PARTICLE	91 +1	143 -1
URANIUM-234	ALPHA PARTICLE	92 -2	142 -2
THORIUM-230	ALPHA PARTICLE	90 -2	140 -2
RADIUM-226	ALPHA PARTICLE	88 -2	138 -2
RADON-222	ALPHA PARTICLE	86 -2	136 -2
POLONIUM-218	ALPHA PARTICLE	84 -2	134 -2
LEAD-214	BETA PARTICLE	82 +1	132 -1
BISMUTH-214	BETA PARTICLE	83 +1	131 -1
POLONIUM-214	ALPHA PARTICLE	84 -2	130 -2
LEAD-210	BETA PARTICLE	82 +1	128 -1
BISMUTH-210	BETA PARTICLE	83 +1	127 -1
POLONIUM-210	ALPHA PARTICLE	84 -2	126 -2
LEAD-206	STABLE ATOM	82	124

FIGURE 2.64.—The decay chain of a uranium atom.

2.65b Thorium 234 emits not an alpha particle but a beta particle. Where does the beta particle come from? Remember that a neutron is electrically neutral. We have seen that an electrically neutral state can be reached when positive and negative charges balance one another and that a neutron can act like a proton with an electron tightly tied onto it as shown in Figure 2.65b.

2.65c The negative charge of the electron balances the positive charge of the proton resulting in a neutron. When this negatively charge electron is ejected as a beta particle the remainder is no longer electrically neutral, but now has a positive charge, thus changing a neutron to a proton. In effect, one proton has been gained and one neutron has been lost. Now there are 91 protons and 143 neutrons. The weight is still 234, but since the number of protons has been changed, the nature of the element has been changed, and is now an atom of protactinium 234.

2.65d Protactinium 234 also emits a beta particle so 1 proton is added, and 1 neutron is subtracted, leaving 92 protons and 142 neutrons. Its weight is 234, but the element is, of course, again uranium because it now has 92 protons.

2.65e Uranium 234 emits an alpha particle, 2 neutrons and 2 protons are subtracted, leaving 230 particles in the nucleus. Since the number of protons is back to 90, the element is now thorium 230.

2.65f Thorium 230 emits an alpha particle. Subtract 2 protons and 2 neutrons. It now has a weight of 226, and since it has

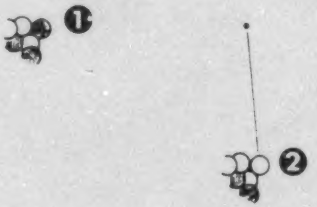


FIGURE 2.65b.—Concept of a neutron changing into a proton by emitting a beta particle.

only 88 protons in the nucleus, it is the element radium.

2.65g Radium emits an alpha particle, so 2 neutrons and 2 protons are lost leaving 86 protons and 136 neutrons. Our element is now radon 222 which is a gas.

2.65h Radon 222 emits an alpha particle, leaving 84 protons and 134 neutrons. Again a different element is formed—polonium 218.

2.65i Polonium emits an alpha particle, which leaves 82 protons and 132 neutrons, and is lead 214.

2.65j Lead 214 emits a beta particle which increases the number of protons by 1 and decreases the number of neutrons by 1, leaving 83 protons and 131 neutrons. This forms bismuth 214.

2.65k Bismuth 214 emits a beta particle which adds 1 proton and subtracts 1 neutron, leaving 84 protons and 130 neutrons. This is polonium 214.

2.65l Polonium 214 emits an alpha particle which takes away 2 neutrons and 2 protons, leaving 82 protons and 128 neutrons for a mass of 210, and the element is lead 210.

2.65m Lead 210 emits a beta particle, leaving 83 protons and 127 neutrons, which now becomes bismuth 210.

2.65n Bismuth 210 emits a beta particle which adds a proton and subtracts a neutron, leaving 84 protons and 126 neutrons. This is polonium 210.

2.65o Polonium 210 emits an alpha, which leaves 82 protons and 124 neutrons. The total weight is 206; the element is lead 206.

2.65p Lead 206 is stable and not radioactive, therefore, this is "the end of the line".

2.66 Well, that's fine, and all very interesting, and accounts for beta and alpha radiation, but what about gamma radiation? Where does that come from? As we saw in paragraph 2.61, gamma radiation originates when the discharge of one of these particles from a nucleus does not take sufficient energy along with it to leave the nucleus in quite a contented state. If the particle leaving the nucleus does not take with it all of the energy that the atom would like to get rid of in this particular disintegration, it throws off some of the energy in the form of gamma radiation. Therefore gamma radiation can be given off by many radioactive materials in addition to the beta or alpha radiation.

2.67 The foregoing makes it clear why gamma radiation occurs and can therefore be detected from a radium dial wrist watch or from uranium ore by a prospector. Both radium and uranium are pure alpha emitters, but as time passes the decay process goes on and forms daughter products in the radium and uranium. It is from the decay of these various radioactive "daughter products" that the gamma radiation is given off. Pure radium or uranium, freshly prepared, represents only an alpha hazard and could safely be handled with the bare hands as far as external hazard is concerned. (Handling it with the bare hands is not a good idea because of the possibility of introducing some radium into the body by this means and, besides, heavy metals are toxic.) After the passage of time, however, the daughter products start to build up and alpha, beta, and gamma radiation are all being given off from the radium and its associated daughters.

INTERACTION OF RADIATION WITH MATTER

NOTE

The important thing to remember about nuclear radiation is that it is a "shooting out" of particles or bits of energy, some large, some small; some fast, some slow; some weak, some powerful. Since everything contains atoms—including our bones, skin, and organs, of course—these particles strike the atoms with force, the amount depending on the kind of particle, and other factors. Actually, since the atom is, as we have seen, made up of an extremely compact core and shells of electron(s), these electrons bear the brunt of the hammering given out when the atom is struck by particles. As will be seen, the electrons react to this hammering in various ways. This has great significance to the study of *radiation safety and the effects of radiation on the body, as you will discover later.*

2.68 Alpha particles lose their energy rapidly and hence have a limited range, only about 6 or 7 centimeters in air, and are completely stopped by a sheet of paper. When the alpha particle is stopped, stabilized, or reaches ground state, it has picked up two electrons which are available in space thus making it a neutral helium atom. The loss of energy by the alpha paricle as it traverses space is due to its high specific ionization, i.e., the number of ion pairs produced per centimeter of path. Each ionization event in air requires about 32–36 ELECTRON VOLTS per ion pair produced. The unit electron volt is the amount of energy acquired by a unit charge of electricity when the charge moves through a potential difference of one volt. For example, if an electron should start at a potential of zero volts and be accelerated to a point having a potential of 32 volts, it would acquire an energy equivalent to 32 electron volts. An electron volt is a very small amount of energy. More common terms are thousand electron volts (keV), and million electron volts (MeV).

2.69 The high specific ionization of alpha particles, 20,000–80,000 ion pairs per centimeter of air traversed, is due to several factors. First, alpha is a relatively large particle and has a high positive charge; hence it will not only collide with other matter, but there will be frequent electrostatic interactions with the electrons associated with the atoms through which the particle is passing. These interactions result in a loss of energy by literally knocking an electron from its orbit (ionization), or it may lose energy to the atom by merely displacing electrons from their normal orbits without ejecting them from the atom (excitation). Figure 2.69 shows the difference between an excited atom and a positive ion.

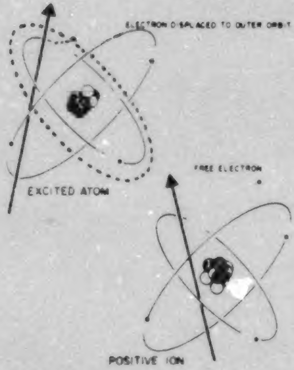


FIGURE 2.69.—Excitation and ionization by an alpha particle.

2.70 In addition to being *large* and *positively charged*, the alpha particle is also comparatively *slow*, and by remaining in the vicinity of the atoms in its path, there is a greater probability of ionizing them. With this loss of energy there is a reduction in speed and hence a steadily increasing amount of ionization, at first slowly and then more rapidly, reaching a maximum and then dropping sharply almost to zero. Figure 2.70 is a representative curve for the specific ionization of alpha particles. The range and specific ionization varies somewhat for different radioactive isotopes due to variation in the energy with which the alpha particle is ejected, 4.0 MeV to 10.6 MeV. However, all alpha particles emitted in a specific nuclear reaction have essentially the same energy, and so the same range.

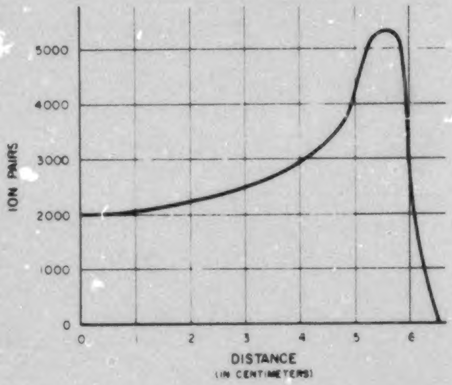


FIGURE 2.70.—Specific ionization of alpha particles.

2.71 The beta particle does not lose its energy as rapidly as the alpha particle. This is due to the fact that it is a very *small* particle, has *less charge* than the alpha particle, and is moving at a *higher rate of speed.* An alpha particle, because of its relatively heavy weight, is not easily deflected and tends to travel in a straight path causing a high degree of ionization. A beta particle, being lightweight is easily bounced around in any material. Therefore, its range in terms of distance from the point of origin to the point where it finally associates itself with an atom may vary considerably. The actual distance traveled by the beta particle also varies to a considerable extent but not as much as the measurement from the point of origin to the point where complete loss of excess energy occurs. Unlike alpha, the beta particles emitted by any given nucleus have a range of velocities and only mean or maximum energies can be assigned to primary beta particles. Tables almost invariably show maximum energies.

2.72 The range of velocities for beta particles ranges from about 25 to 99 percent of the speed of light, with corresponding energy variations from 0.025 MeV to 3.15 MeV with a majority of them being in the vicinity of 1 MeV. The range of the beta particle is proportional to its energy. Therefore, a 3 MeV beta particle will travel further than a 1 MeV beta particle.

2.73 Range is only approximately inversely proportional to the density of the absorbing material through which it passes, i.e., the more dense, the higher the Z number, the more effective that material will be in stopping beta particles. However, because of the emission of X-rays when beta particles react with high Z number materials, low Z number materials such as aluminum, glass and plastics are normally used as beta shields.

2.74 The specific ionization of beta particles is approximately 50-500 ion pairs per centimeter in air varying according to the energy of the beta particle and the density of the absorbing material. The range of beta particles in air would be several meters. Thus, compared to the few-centimeter range of alpha in air, beta has a long range.

2.75 Gamma rays *do not consist of particles, have no mass, travel at the speed of light* and hence *do not lose their energy as rapidly as either alpha or beta particles.* Gamma rays or photons *produce no direct ionization by collision* as alpha and beta because *gamma rays have no mass.* They are absorbed or lose their energy by three processes known as the PHOTOELECTRIC EFFECT, the COMPTON EFFECT, and PAIR PRODUCTION.

RADIATION	RANGE IN AIR	SPEEDS	SPECIFIC IONIZATION
ALPHA	5-7 cm	2,000-20,000 MI/SEC	[illegible]0,000-80,000 ion pairs/cm
BETA	200-800 cm	25-99% SPEED OF LIGHT	50-500 ion pairs/cm
GAMMA	USE OF HALF-THICKNESS	SPEED OF LIGHT 186,000 MI/SEC	5-8 ion pairs/cm

FIGURE 2.74.—Characteristics of nuclear radiation.

2.76 Gamma rays are *highly penetrating,* their *effective range depending on their energy.* The effect of air on a gamma ray is so small that it is not practical to measure the range of gamma radiation in terms of inches, feet, or meters, but its penetrating power is measured in terms of the amount of material that will be required to reduce the gamma ray to some fraction of its original value.

2.77 As a gamma ray or photon passes through an atom it may transfer all of its energy to an orbital electron ejecting it

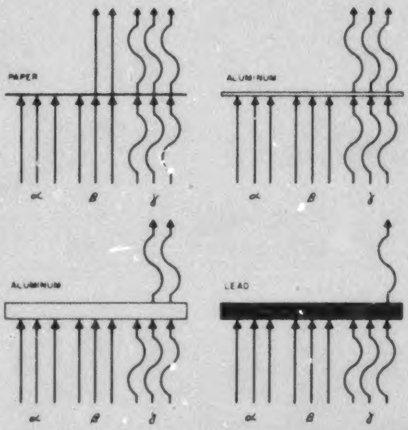


FIGURE 2.76.—Penetration-absorption of nuclear radiation.

from the atom. If the photon carries more energy than necessry to remove the electron from its orbit, this excess energy can be transferred to the electron in the form of kinetic energy. Figure 2.77 shows electrons ejected in this manner. These are referred to as PHOTOELECTRONS, and the process by which this transfer of energy was accomplished is known as the PHOTOELECTRIC EFFECT. Since the orbital electron in this case has completely absorbed the energy of the gamma ray, the photon disappears. The photoelectron will ultimately lose its energy through the formation of ion pairs. The photoelectric effect generally occurs with low energy gamma photons of approximately one-tenth MeV or less.

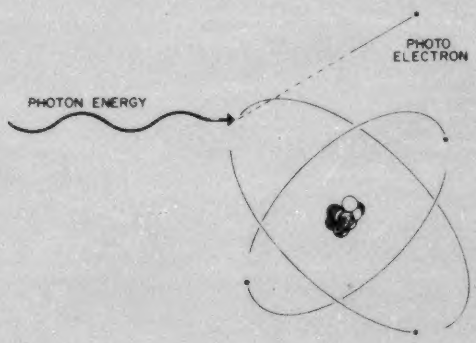


FIGURE 2.77.—Absorption of gamma radiation by the photoelectric effect.

2.78 The COMPTON EFFECT does not completely absorb the energy of the gamma ray. A gamma ray loses a part of its energy to a free or loosely bound orbital electron but will continue as a scattered gamma photon of lower energy. *The energy of this photon will equal the difference in original energy less the amount of energy transferred to the electron.* The gamma photon reacting with an orbital electron *acts* as though it had mass since it causes the electron to be ejected with high energy and a lower energy photon rebounds at some angle. Both the electron which is ejected at an angle to the path of the original gamma photon and the lower energy gamma photon which is also scattered at an angle may cause further ionization. Figure 2.78 shows the Compton effect. This effect occurs with intermediate gamma photons of approximately one-tenth to one MeV.

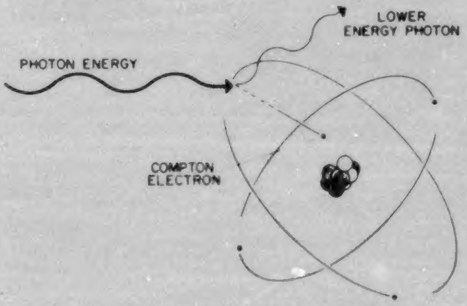


FIGURE 2.78.—Absorption of gamma radiation by the Compton effect.

2.79 PAIR PRODUCTION occurs only with high-energy gamma rays. In this process, as the photon approaches the nucleus of the absorbing atom, it *completely converts itself into a* pair of electrons. One of these is called a NEGATRON but actually is an ordinary electron with a negative charge. The other particle which has exactly the same mass as the negatron (electron) but carries a positive charge rather than a negative charge is known as a POSITRON and is designated by the symbol e+. This process requires gamma rays with a minimum energy of 1.02 MeV, and at energy levels above this the possibility of this interaction increases. Figure 2.79 is a diagram of this reaction.

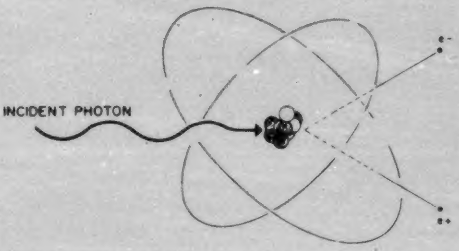


FIGURE 2.79.—Absorption of gamma radiation by pair production.

2.80 Energy in excess of 1.02 MeV is shared by the negatron-positron pair in the form of kinetic energy. The positron usually acquires somewhat more energy than the negatron. *This process is often used as an example of Einstein's mass-energy theory* (E = mc², see paragraph 2.5), since it is an example of the creation of matter (the pair of electrons) out of pure energy (the gamma ray). It has been found that the mass of one electron is equal to 0.51 MeV. Since the pair production process involves the conversion of energy to a negatron-positron pair, the energy required must be at least two times the energy equivalent of one electron, 0.51 MeV. Any energy in the photon that is in excess of 1.02 MeV causes the ejected particles to have greater kinetic energy. The negatron is now equal to the beta particle, usually a very energetic beta particle, and will react and be stabilized in the same manner as previously explained. The positron has an extremely short life, which is ended by combining with an electron. However, before this happens it will cause ionization of other atoms. When the positron does join an electron they are annihilated with the production of two gamma photons of 0.51 MeV each, which eventually will be absorbed by Compton or photoelectric effect.

CURIES AND ROENTGENS

> To be effective in your radiological defense work, you must get a firm grasp on the ways radiation is measured. "Radiation", like "distance" is a general concept. You would have a weak understanding of distance if you were vague about "foot", "inch", "mile", "kilometer", "light year" and the other ways by which distance is measured. The same is true for radiation.

2.81 The CURIE (Ci) is the unit used to measure the activity of all radioactive substances. It is a measurement of rate of decay or nuclear disintegration that occurs within the radioactive material. The curie initially established the activity (that is, the decay rate) of radium as the standard with which the activity of any other substance was compared.

2.82 By using a formula that takes into account the number of atoms per gram and the value of the half-life in seconds, scientists have determined that the activity of radium is equal to 3.7×10^{10} nuclear disintegrations per gram per second. This value is now the standard unit of comparison. A curie of *any* radioactive isotope, therefore, is *the amount of that isotope that will produce 3.7×10^{10}* nuclear disintegrations per second. Since the measure is based on number of disintegrations, the weight of the radioisotope will vary from that of radium. A curie of pure Co^{60} would weigh less than 0.9 milligrams, while a curie of U^{238} would require over two metric tons. The curie is a relatively large unit. In training, a millicurie, mCi (one-thousandth curie) and the microcurie, MCi (one-millionth curie) are common units in use. At the opposite extreme, the curie is too small a unit for convenient measurement of the high-order activity produced by a nuclear explosion. For this purpose, the megacurie (one million curies) is used.

2.83 The ROENTGEN (R) by definition measures exposure to gamma and X-rays. It is an expression of the ability of gamma or X-ray radiation to ionize air. One R will produce 2.083×10^{9} ion pairs per cubic centimeter of air or 1.61×10^{12} ion pairs per gram of air. (See Par 4.13 for a more complete discussion.)

> The curie measures radioactivity.
> The roentgen measures X or gamma radiation.

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EFFECTS OF NUCLEAR WEAPONS

After our introduction to the language of nuclear physics, we are ready to use some of these terms in arriving at an understanding of a nuclear detonation and a knowledge of what can be expected from a nuclear detonation. This is our primary objective and in reaching it, we will also cover:

WHAT	is a chain reaction
WHEN	does it occur
HOW	is it like a chemical explosion
HOW	is it different
WHAT	is fission and fusion
HOW	a nuclear weapon works
WHAT	are the effects of a nuclear explosion
WHAT	is fallout

FAMILIARITY BREEDS CONTROL

3.1 During World War II many large cities in England, Germany, and Japan were subjected to terrific attacks by high-explosive and incendiary bombs. Before the war, it was fully expected that such attacks would cause great panic among the civilian residents of bombed cities. Observations during the attacks and subsequent detailed studies, however, fail to bear out this expectation. The studies showed that when proper steps were taken for the protection of the civilian population and for the restoration of services after the bombing, there was little, if any, evidence of panic. In fact, when such measures are taken, the studies showed that there was a *definite decline in overt fear reactions as the air bombings continued, even when the raids become heavier and more destructive.*

3.2 The history of nuclear defense may be said to have started with the explosion of the two bombs over Japan in August, 1945.

These, the first and only nuclear weapons ever used against an enemy, caused unprecedented casualties. Many of these casualties could have been prevented if there had been sufficient warnings to permit clearing the streets, and if the people of Hiroshima and Nagasaki had known what to expect and what to do. For example, only 400 people out of a population of almost a quarter of a million were inside the excellent tunnel shelters at Nagasaki that could well have protected 75,000 people.

3.3 Information accumulated at Alamogordo, Hiroshima, Nagasaki, Bikini, Eniewetok, and Nevada, as well as experience gained from other types of warfare, has contributed to the store of defensive knowledge. From this knowledge, methods of coping with a nuclear weapon attack have been, and are being devised.

NUCLEAR WEAPON DETONATION VS. HIGH EXPLOSIVE DETONATION

3.4 The nuclear bomb was designed as a blast weapon. Therefore, although immensely more powerful, it resembles bombs of the conventional type, insofar as its destructive effect is due mainly to the blast or shock that follows the detonation. However, nuclear detonations *do* differ from conventional detonations in four important respects:

First—a fairly large amount of the energy from a nuclear detonation is emitted as THERMAL RADIATION, generally referred to as LIGHT and HEAT;

Second—the explosion is accompanied by highly-penetrating, harmful but IN-

VISIBLE NUCLEAR RADIATIONS;

Third—the nuclear reaction PRODUCTS, which remain after the detonation, are RADIOACTIVE, emitting radiations capable of producing harmful consequences in living organisms;

Fourth—nuclear explosions can be many thousands (or millions) of times more powerful than the largest conventional detonations.

PRINCIPLES OF A CHEMICAL DETONATION

3.5 Before the discovery of how nuclear energy could be released for destructive purposes, the explosive material in bombs of the type in general use, often referred to as conventional bombs, consisted largely of atoms of the elements carbon, nitrogen, hydrogen, and oxygen, in TNT (trinitrotoluene) or of a related chemical material. These explosive substances are unstable in nature, and are easily broken up into more stable molecules. This process is associated with the liberation of a relatively large amount of energy, mainly as heat. Once the decomposition of a few molecules of TNT is initiated, by means of a suitable detonator, the resulting shock causes still more molecules to decompose. As a result, the overall rate at which TNT molecules break up is very high. This type of behavior is characteristic of many explosions, the process being accompanied by the liberation of a large quantity of energy in a very short period of time within a limited space.

3.6 The products of the decomposition of conventional explosives are mainly nitrogen and oxides of nitrogen, oxides of carbon, water vapor, and solids, notably carbon, which are readily dissipated in the surrounding air. Therefore, the substances remaining after the explosion do no more harm than the poisonous carbon monoxide present in the exhaust gases when automobile and airplane engines are operated in the open air.

3.7 With a conventional explosive the chemical molecules comprising the various atoms are held together by certain forces, sometimes referred to as valence bonds. When the molecules undergo decomposition, there is a rearrangement of the atoms, and there is a change in the character of the valence bonds. As stated above, a chemical explosive is an unstable compound, and in it the valence forces are relatively weak. In the molecules of the decomposition products, however, the same atoms are bound more strongly. It is a law of physics that the conversion of any system in which the constituents are held together by weak forces into one in which the forces are stronger, must be accompanied by the release of energy. Consequently, the decomposition of an unstable chemical explosive results in the liberation of energy.

PRINCIPLES OF NUCLEAR DETONATIONS

3.8 An atomic or nuclear explosion resembles chemical explosions in the respect that it is due to the *rapid release of a large amount of energy*. But the difference lies in the fact that in the nuclear explosion, the energy results from *rearrangement within the central portion*, or *nucleus* of the atom, rather than among the atoms themselves as in a chemical explosion. Since the forces existing between the protons and neutrons in the nucleus are much greater than the forces between the atoms in a molecule of chemical explosive material, energy changes, accompanying nuclear rearrangements are very much greater than those associated with chemical reactions.

3.9 The basic requirement for energy release is that the total mass of the interacting species should be greater than that of the resultant product (or products) of the reaction. As we saw in Chapter II, there is a definite equivalence between mass and energy. Thus, when a decrease of mass occurs in a nuclear reaction, there is an accompanying release of a certain amount of energy related to the decrease in mass. In addition to the necessity for the nuclear process to be one in which there is a net decrease in mass, the release of nuclear energy in amounts sufficient to cause an explosion requires that the reaction should be able to *reproduce itself* once it has been started. Two types of nuclear

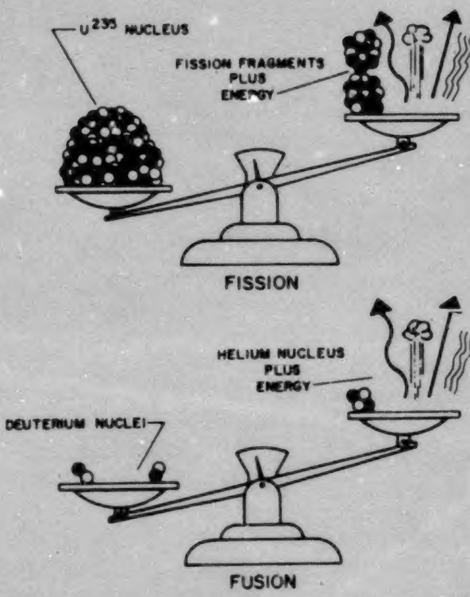

FIGURE 3.9.—Fission and fusion.

interactions which can meet the requirements for the production of large amounts of energy in a short time are FISSION and FUSION. The fission process takes place with some of the heaviest nuclei (high atomic number), whereas the fusion process involves some of the lightest nuclei (low atomic number). (See Figure 3.9.)

NUCLEAR FISSION

3.10 The fissile materials which can presently be used to produce nuclear explosions are the uranium isotopes U^{233}, U^{235}, and the plutonium isotope Pu^{239}. When a neutron enters the nucleus of the appropriate atom, the nucleus splits (fissions) into two daughter nuclei and two to three neutrons (Figure 3,10). For U^{233}, U^{235}, and Pu^{239}, unlike the case for U^{238}, there is no lower limit for the kinetic energy that a neutron must possess to enable it to cause fission on capture by a nucleus of any of these three isotopes. For this reason, these isotopes are called fissile materials, and only these three are of practical significance. In the case of a nonfissile nucleus, the energy of the incident neutron must exceed a certain threshold value to enable it to cause fission or capture. The threshold values for U^{238} and Th^{232} (Thorium 232) are nearly 0.9 MeV and 1.1 MeV respectively. Generally speaking, any heavy nucleus can undergo fission if the excitation energy is large enough, e.g., fission of gold occurs with neutrons of about 100 MeV energy.

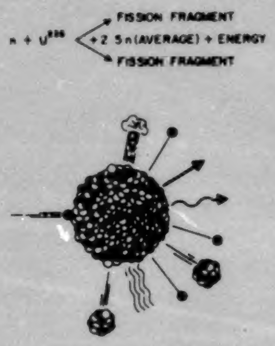

FIGURE 3.10.—Fission of uranium 235 produces neutrons.

FISSION CHAIN REACTION

3.11 In addition to the large amount of energy released in nuclear fission, the second important fact, which has made possible the production of an explosion as a result of fission, is that the *process is accompanied by the release of two or more* NEUTRONS (Figure 3.10). The neutrons thus liberated in the fission process are able to cause the fission of other uranium or plutonium nuclei. In each case more neutrons are released, which can produce further fission, and so on. Hence, a single neutron could start a self-sustained[1] chain of fissions, the number of nuclei involved increasing at a tremendous rate.

3.12 Actually, not all the neutrons liberated in the fission process are available for causing more fissions. Some of these neutrons escape and others are lost in non-fission reactions. It will be assumed, however, for simplicity, that for each uranium (or plutonium) nucleus undergoing fission, there are two neutrons produced capable of initiating further fission. Suppose a single neutron is captured by a nucleus in a quantity of uranium, so that fission occurs. Two neutrons are then liberated and these cause two more nuclei to undergo fission. This results in the production of four neutrons available for fission. The fissions increase by geometric progression (1,2,4,8,16,32,64,128,256,512,1024,2048,4096, and so on). By the eighty-first step of this process, we have 2.5×10^{24} fissions—enough to fission a kilogram of refined uranium. The time required for the 81 steps is $^{1}/_{10^{8}}$ seconds. As you can see, this tremendous activity takes place almost instantaneously, thus producing an explosive reaction.

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[1] A self-sustained chain reaction in pure U^{238} or pure Th^{232} or natural uranium is not possible.

3.13 The actual loss of mass in the fission of uranium or plutonium is only about one-tenth of a percent of the total. That is, if all the atomic nuclei in one pound of uranium or plutonium undergo fission, the decrease of mass would be roughly five-tenths of a gram or one-sixtieth part of an ounce. Nevertheless, the amount of energy released by the disappearance of this quantity of matter would be about the same as that produced by the explosion of 8,000 tons of TNT.

CRITICAL SIZE OF NUCLEAR FISSION BOMB

3.14 When a piece of fissile material is below a certain size, a few of the atoms are continually undergoing fission, but more neutrons escape through its surface than are produced in fission, and an increasing chain of fissions is not built up. Such a mass is called SUBCRITICAL. On the other hand, when a mass (in a given shape) is just great enough to support a sustaining chain reaction, it is called a CRITICAL mass. As we can readily see, then, if several pieces of fissile material, totalling more than the critical amount, are suddenly brought together inside a strong container or TAMPER (see Figure 3.14) a nuclear detonation results.

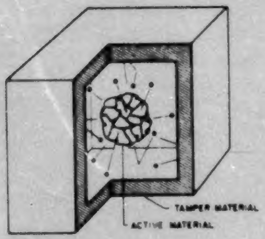

FIGURE 3.14.—Tamper

What constitues a CRITICAL mass depends upon a number of factors, including the density of the material (whether solid metal or in porous, spongy form); and also upon the nature of the TAMPER and whether it absorbs neutrons or can reflect them back into the fissile charge.

3.15 Published information suggests that an unconfined sphere of U^{235} metal of about 6$^{1}/_{2}$ inches diameter and weighing about 48 kilograms would be a critical amount; this would be reduced to about 4$^{1}/_{2}$ inches diameter (16 kg.) for a U^{235} sphere enclosed in a heavy tamper (Figure 3.14). The critical sizes for U^{233} and Pu^{239} have not been disclosed. The increasing mechanical complication of bringing together, rapidly and simultaneously, a number of subcritical pieces of fissile material, sets a practical limit to the power of nuclear fission weapons. Another important consideration is that the size of a purely fission-type bomb is limited because, above a certain critical size, a lump of fissile material is self-destructive.

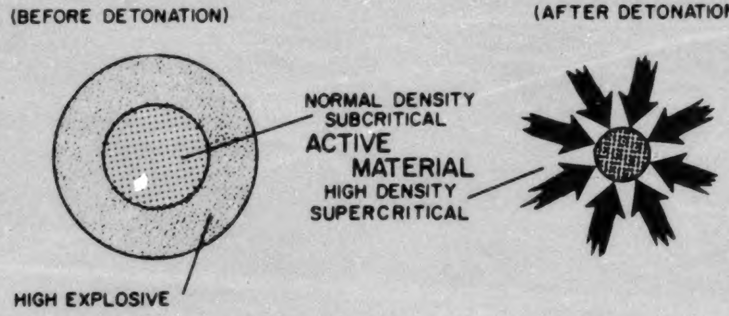

FIGURE 3.16a. —Implosion principle.

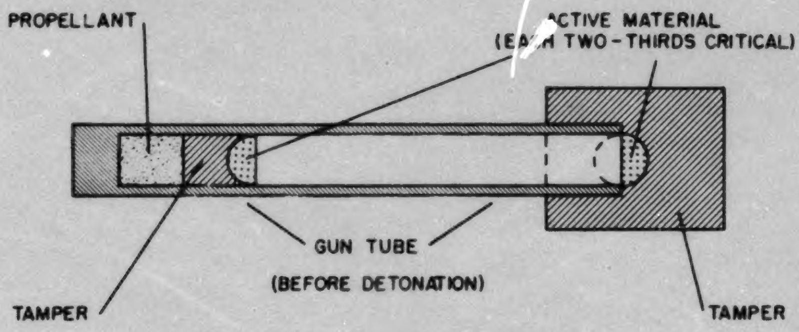

FIGURE 3.16b.—Gun assembly principle.

3.16 As we have seen, subcritical masses or pieces of fissile material, when brought together rapidly can, under proper conditions, cause a chain reaction and subsequent explosion. As a very necessary safety precaution, it is obvious that the masses of fissionable material present in a nuclear bomb must be *kept subcritical* until time for the bomb to be detonated. And when that time arrives, the subcritical masses must form a supercritical mass instantaneously. One way of producing a supercritical mass is by forcing two or more subcritical masses together. Another way is to squeeze a subcritical mass tightly into a new shape and/or a greater density. Such a mass becomes supercritical without the addition of any more substance. This latter method, first used in a crude form in the Nagasaki bomb, is called the implosion principle (Figure 3.16a). In this bomb, a given amount of fissile material, subcritical in the form of a thin spherical shell, became critical when compressed into a solid sphere. This compression was brought about by firing specially fabricated shapes of ordinary high explosive arranged spherically on the outside surface of the hollow sphere. When the explosive is detonated, the mass is compressed, immediately becoming supercritical and the atomic detonation takes place. The other method was used with the Hiroshima bomb. The subcritical masses, enclosed in something like a gun barrel, were impelled against each other by the action of regular chemical explosives (Figure 3.16b).

FISSION AND FUSION . . . AND THERMONUCLEAR WEAPONS

3.17 A fission explosion produces—briefly and in a small space—intensities of light and heat comparable to those in the sun. A fusion explosion does still more: it duplicates a part of the actual process by which the sun and other stars produce their light and heat. This process is not a chemical burning reaction. It is a nuclear fusion reaction in which four nuclei of simple hydrogen become one nucleus of stable helium, with a conversion of mass to radiant energy. Through this process our sun, every second, loses about 4 to 5 million tons of matter, radiated as energy. From experiments made in laboratories with cyclotrons and similar devices, it was concluded that man could partially duplicate the process of the sun, by the fusion of isotopes of hydrogen. This element is known to exist in three isotopic forms in which the nuclei have masses of 1, 2, and 3, respectively. These are generally referred to as hydrogen (H^1), deuterium (H^2 or D^2), and tritium (H^3 or T^3). Several different fusion reactions have been observed among the nuclei of the three hydrogen isotopes, involving either two similar or two different nuclei. In order to make these reactions occur to an appreciable extent, the nuclei must have high energies. One way in which this energy can be supplied is by means of a charged-particle accelerator, such as a cyclotron, as mentioned earlier. Another possibility is to raise the temperature to very high levels. In these circumstances, the fusion processes are referred to as "thermonuclear reactions".

3.18 Temperatures of the order of a million degrees are necessary in order to make the nuclear fusion reactions take place. The only known way in which such temperature can be obtained on earth is by means of a fission explosion. At temperatures of millions of degrees centigrade, atoms are stripped of most of their surrounding cloud of electrons and the nuclei move at very high speeds experiencing many collisions with one another. Under these circumstances, the nuclei of the rarer hydrogen isotopes deuterium and tritium have enough energy of motion to overcome the repulsive forces between their single positive electrical charges and they are able to fuse together. The energy released in the fusion of these two nuclei is about one-twelfth of that released in the fission of a single U^{235} nucleus; but on an equal weight basis, the fusion energy is about three times as large as the energy of fission of U^{235}. The actual quantity of energy liberated, for a given mass of material, depends on the particular isotope (or isotopes) involved in the nuclear fusion reaction. Four thermonuclear fusion reactions are noted below:

$$H^2 + H^2 \rightarrow He^3 + n + 3.25 \text{ MeV}$$

$$H^2 + H^2 \rightarrow H^1 + H^3 + 4.03 \text{ MeV}$$

$$H^3 + H^2 \rightarrow He^4 + n + 17.58 \text{ MeV}$$

$$H^3 + H^3 \rightarrow He^4 + 2n + 11.32 \text{ MeV}$$

where He is the symbol for helium and n (mass = 1) represents a neutron. The energy liberated in each case is expressed in million-electron-volts (MeV).

3.19 Used alone, deuterium and tritium, as isotopes of the gaseous element hydrogen, have to be liquefied at a very low temperature and maintained there for containment in a thermonuclear device. This is inconvenient although it has been reported that the first American thermonuclear device tested in 1952 was of this type. In later weapons the deuterium is combined chemically with the metal lithium in the form of a white powder. Each neutron (1 mass unit) released by the triggering fission bomb splits a lithium atom (6 mass units) into the non-radioactive gas helium (4 mass units) and tritium (3 mass units), and the latter fuses with the deuterium atoms present in the compound (Figure 3.19). There is no limit, other than the convenience of delivery, to the size of a fusion or thermonuclear weapon, and it is claimed that lithium deuteride is less costly than fissile materials such as U^{233}, U^{235} or Pu^{239}.

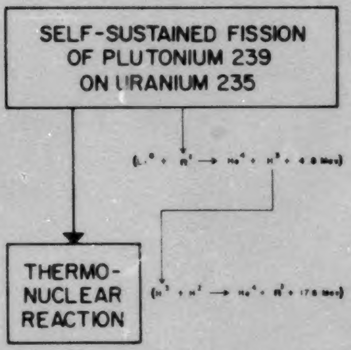

FIGURE 3.19.—Fission-fusion reaction.

3.20 In considering weapon designs, it is possible also to have a fission-fusion-fission type weapon (Figure 3.20). In the process of fusion, a neutron is released at a very high speed and it has enough energy to split the commoner atoms of U^{238}. A thermonuclear weapon can be designed with a core of fissile U^{235} as a fusion initia-

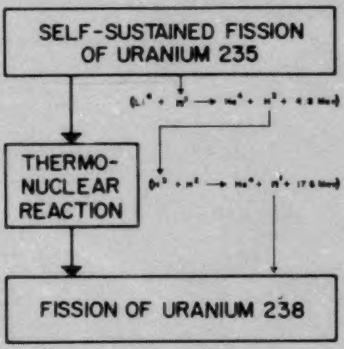

FIGURE 3.20.—Fission-fusion-fission reaction.

tor encased in a heavy container of U^{238}. This U^{238} casing will undergo fission from the high-speed neutrons produced in the hydrogen fusion detonation. Since the casing might be many times heavier than the fissile core of U^{235}, correspondingly larger quantities of fission products would be released as fallout from such a weapon.

3.21 A much more detailed discussion of fission products will be taken up later in this chapter, but it might be mentioned here that all existing types of nuclear weapons release fission products. "Dirty" bombs produce a great deal and "clean" bombs produce little, the dirtiness depending upon the ratio of fission to fusion energy produced by the bomb. The dividing line between "clean" and "dirty" bombs is, thus, a matter of opinion, but the fission-fusion-fission type of weapon mentioned in paragraph 3.20 would be a relatively "dirty" one.

ENERGY YIELD OF A NUCLEAR EXPLOSION

3.22 The power of a nuclear detonation is expressed in terms of the total amount of energy released as compared with the energy liberated by TNT when it explodes. A 1-kiloton nuclear detonation is one which releases energy equivalent to 1,000 tons of TNT which is called the kiloton (KT). The advent of thermonuclear hydrogen bombs made it desirable to use a unit about 1,000 times larger still, and the megaton (MT) unit was adopted. It is equivalent to the energy released by the detonation of 1,000,000 tons of TNT. The bombs detonated over Hiroshima and Nagasaki, and those used in the 1946 test at Bikini, released roughly the same amount of energy as 20,000 tons (or 20 kilotons) of TNT. In recent years, much more powerful weapons, with energy yields high in the megaton range, have been developed.

DISTRIBUTION OF ENERGY

3.23 Although the detonation of chemical explosives, such as TNT, and the detonation of a nuclear weapon both produce heat or thermal radiation, the proportion as well as the quantity is much higher in the case of the nuclear weapon. The basic reason for this difference is that, weight for weight, the energy produced in a nuclear explosion is millions of times as great as that in a chemical explosion. Consequently, the temperatures reached in the nuclear explosion are much higher than in a chemical explosion—tens of millions of degrees in a nuclear explosion compared with a few thousands in a chemical explosion.

3.24 For a nuclear detonation in the atmosphere below 100,000 feet, about 85 percent of the total energy appears first as intense heat. As shown in Figure 3.24, almost immediately a considerable part of this heat is converted to blast or shock; the remaining thermal energy moves radially outward at the speed of light as heat and visible light. The remaining 15 percent of the energy of the nuclear explosion is released as various nuclear radiations. Of this, 5 percent constitutes the nuclear radiation produced within a minute or so of explosion, whereas the final 10 percent of the bomb energy is in the form of residual radiation emitted over a period of time. The residual radiation includes the FALLOUT we will discuss in later chapters.

TYPES AND HEIGHTS OF NUCLEAR DETONATIONS

3.25 As we have seen, an explosion is the release of a large quantity of energy in a short interval of time within a limited

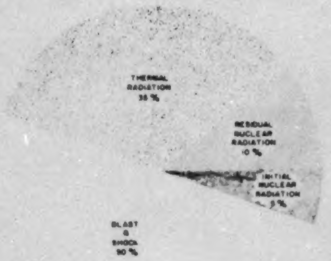

FIGURE 3.24.—Distribution of energy in a typical air burst of a fission weapon in air at an altitude below 10,000 feet.

space. The liberation of this energy is accompanied by a considerable increase in temperature, so that the products of the explosion become extremely hot gases. These gases, at high temperature and pressure, move outward rapidly. In doing so, they push away the surrounding medium—air, earth, or water—with great force, thus causing the destructive (blast or shock) effects of the explosion. The term "blast" is generally used for the effect in air, because it resembles (and is accompanied by) a very strong wind. In water or under the ground, however, the effect is referred to as "shock" because it is like a sudden impact.

3.26 The immediate phenomena associated with a nuclear explosion, as well as the effects of shock and blast, and thermal and nuclear radiation, vary with the location of the point of burst in relation to the surface of the earth. For each weapon of specific power, there is a critical height of burst above which the fireball will not touch the ground and, hence, it will not produce appreciable contamination on the earth's surface. Although many variations and intermediate situations can arise in practice, for descriptive purposes three types of bursts are distinguished. The main types, which will be defined below, are air, surface, and sub-surface burst.

CHARACTERISTICS OF AN AIR BURST

3.27 An air burst (frequently the most efficient means of accomplishing a military objective, and the type used over Japan) is defined as one in which the bomb is exploded in the air, above land or water, at such a height that the fireball (at maximum brilliance) does not touch the surface. The aspects of an air burst will be dependent upon the actual height of the explosion, as well as upon the energy yield of the weapon, but the general phenomena are much the same in all cases.

3.28 In the following discussion, it will be supposed first, that the weapon detonation takes place in the air at a considerable height above the surface. The descriptions given here refer mainly to the phenomena accompanying the explosion of a 1-megaton TNT equivalent nuclear bomb. The important aspects of a nuclear explosion in the air are summarized in Figures 3.28a to 3.28e.

THE FIREBALL

3.29 As already seen, nuclear reactions involving fission and fusion in a nuclear weapon lead to the liberation of a large amount of energy in a very short period of time within a limited space. As a result, the nuclear reaction products, bomb casing, other weapon parts, and surrounding air are raised to extremely high temperatures, approaching those in the center of the sun. Due to the great heat produced by the nuclear explosion, all the materials are converted into the gaseous form. Since the gases, at the instant of explosion, are restricted to the region occupied by the original constituents in the bomb, tremendous pressures will be produced. These pressures are many hundreds of thousands times the atmospheric pressure,[2] i.e., of the order of millions of pounds per square inch.

3.30 Within a fraction of a second of the detonation of the bomb, the intensely hot gases at extremely high pressure appear as a roughly spherical, highly luminous mass. This is the fireball referred to in paragraph 3.26. A typical fireball accompanying an air burst is shown in Figure 3.28a. Although the brightness decreases with time, after about a millisecond,[3] the fireball of a 1-megaton nuclear bomb explosion would appear to an observer 60 miles away to be *many times as bright as the sun at noon.*

3.31 As a general rule, the luminosity of the fireball does not vary greatly with the yield (or power) of the bomb. The surface temperatures attained, upon which the brightness depends, are thus not very different, in spite of differences in the total amounts of energy released.

3.32 Immediately after its formation, the fireball begins to enlarge in size, engulfing cooler surrounding air. The growth in size of the fireball is accompanied by a decrease in temperature (and pressure) and, hence, in luminosity. At the same time, the fireball rises, much like a fiery doughnut. As it rises, there are updrafts through the center of the doughnut and downdrafts on the outside.

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[2] The normal atmospheric pressure at sea level is 14.7 pounds per square inch (PSI).

[3] A millisecond is one-thousandth part of a second.

3.33 Within seven-tenths of a millisecond from the detonation, the fireball from a 1-megaton bomb reaches a radius of about 220 feet, and this increases to a maximum of about 3,600 feet in 10 seconds. The diameter is then some 7,200 feet and the fireball is rising at the rate of 250 to 350 feet per second. One minute after detonation, the fireball has cooled, due to the emission of heat and entrainment of cool air, to such an extent that it is no longer luminous. It has, by this time, risen roughly 4.5 miles from the point of burst.

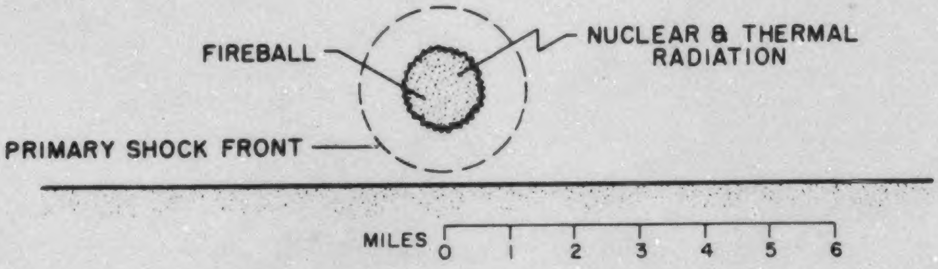

FIREBALL
NUCLEAR & THERMAL RADIATION
PRIMARY SHOCK FRONT
MILES
0
1
2
3
4
5
6

FIGURE 3.28a.—Chronological development of an air burst: 1.8 seconds after 1-megaton detonation.

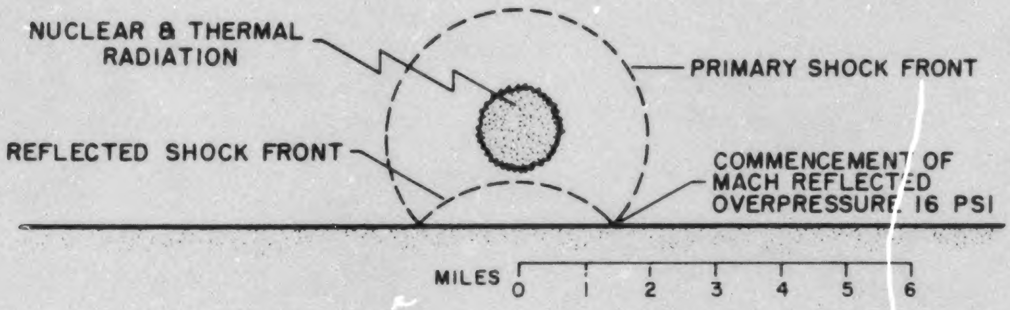

NUCLEAR & THERMAL RADIATION
PRIMARY SHOCK FRONT
REFLECTED SHOCK FRONT
COMMENCEMENT OF MACH REFLECTED OVERPRESSURE 16 PSI
MILES
0
1
2
3
4
5
6

FIGURE 3.28b.—Chronological development of an air burst: 4.6 seconds after 1-megaton detonation.

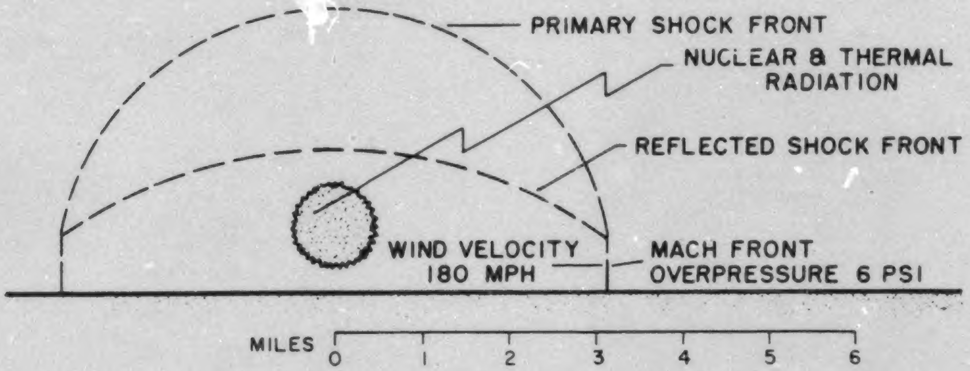

PRIMARY SHOCK FRONT
NUCLEAR & THERMAL RADIATION
REFLECTED SHOCK FRONT
WIND VELOCITY 180 MPH
MACH FRONT OVERPRESSURE 6 PSI
MILES
0
1
2
3
4
5
6

FIGURE 3.28c.—Chronological development of an air burst: 11 seconds after 1-megaton detonation.

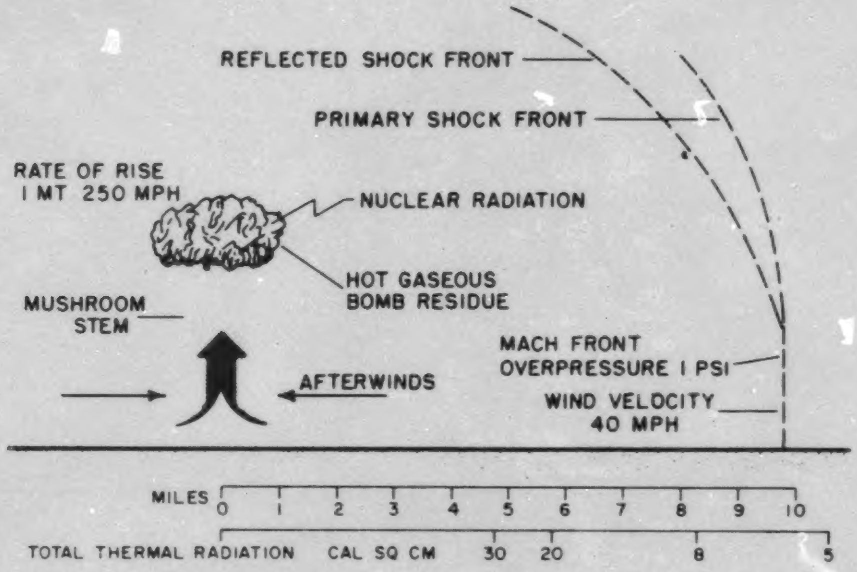

REFLECTED SHOCK FRONT
PRIMARY SHOCK FRONT
RATE OF RISE
1 MT 250 MPH
NUCLEAR RADIATION
HOT GASEOUS
BOMB RESIDUE
MUSHROOM
STEM
AFTERWINDS
MACH FRONT
OVERPRESSURE 1 PSI
WIND VELOCITY
40 MPH
MILES
0 1 2 3 4 5 6 7 8 9 10
TOTAL THERMAL RADIATION CAL SQ CM
30 20 8 5

FIGURE 3.28d.—Chronological development of an air burst: 37 seconds after 1-megaton detonation.

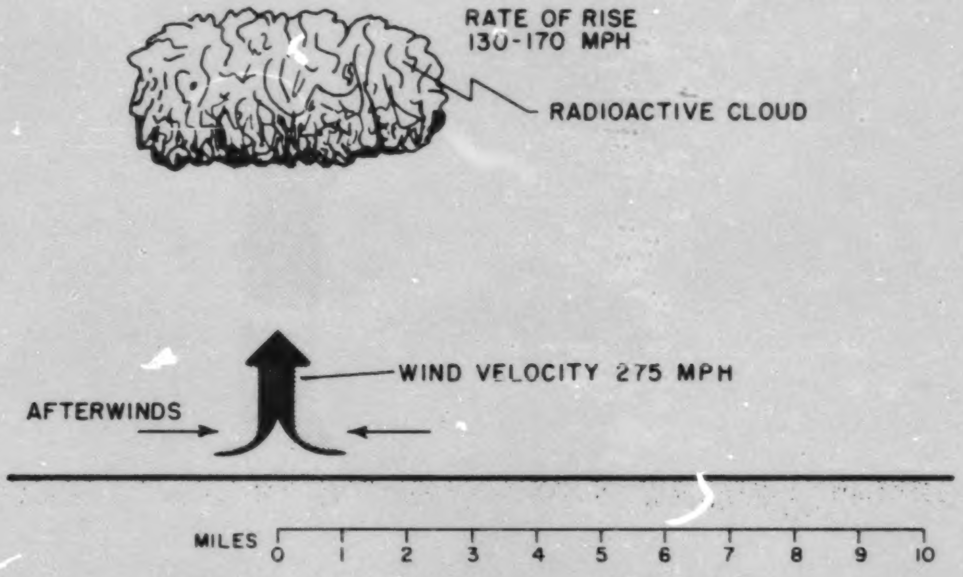

RATE OF RISE
130-170 MPH
RADIOACTIVE CLOUD
WIND VELOCITY 275 MPH
AFTERWINDS
MILES
0 1 2 3 4 5 6 7 8 9 10

FIGURE 3.28e.—Chronological development of an air burst: 110 seconds after 1-megaton detonation.

THE BLAST WAVE

3.34 At a fraction of a second after the explosion, a destructive high-pressure wave develops in the air around the fireball and moves rapidly away, behaving like a moving wall of highly compressed air. After the lapse of 10 seconds, when the fireball of a 1-megaton nuclear bomb has attained its maximum size (7,200 feet across), the blast front is some 3 miles further ahead. About a minute after the explosion, when the fireball is no longer visible, the blast wave has traveled approximately 12 miles. It is then moving at about 1,150 feet per second, which is slightly faster than the speed of sound at sea level.

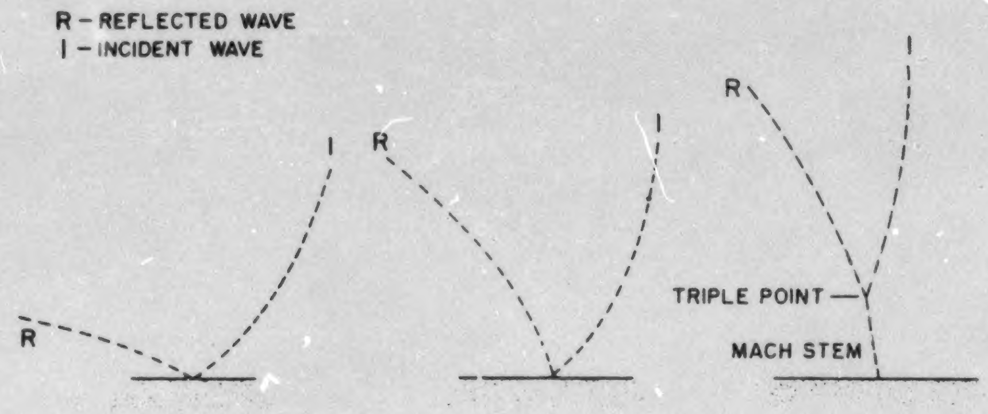


FIGURE 3.35.—Fusion of incident and reflected waves and formation of Mach stem.

THE MACH WAVE

3.35 When the blast wave strikes the surface of the earth, it is reflected in a way similar to a sound wave producing an echo. This reflected blast wave, like the original (or direct) wave, is also capable of causing material damage. At a certain region on the surface, the position of which depends chiefly on the height of the burst above the surface and the energy of the explosion, the direct and reflected blast fronts fuse as shown in Figure 3.35. This fusion phenomenon is called the MACH EFFECT. The OVERPRESSURE, i.e., the pressure of the blast wave in excess of the normal atmospheric value, at the front of the Mach wave is generally about twice as great as that at the direct shock front. The maximum overpressure value, i.e., at the blast front, is called the *Peak overpressure*.

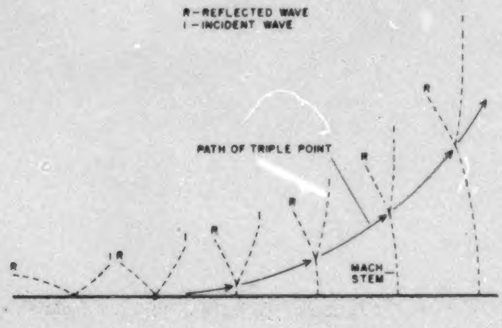


FIGURE 3.37.—Outward motion of the blast wave near the surface in the Mach region.

3.36 For a "typical" air burst of a 1-megaton nuclear weapon, the Mach effect will begin approximately 5 seconds after the explosion, in a rough circle at a radius of 1.3 miles from ground zero. The term "GROUND ZERO" refers to the point on the earth's surface immediately below (or above) the point of detonation.

3.37 At first, the height of the Mach front is small (Figure 3.37), but as the blast front continues to move outward, the height increases steadily forming a MACH STEM. During this time, however, the overpressure, like that in the original blast wave, decreases correspondingly because of the continuous loss of energy and the ever-increasing area of the advancing front. After the lapse of about 40 seconds, when the Mach front from a 1-megaton nuclear bomb is 10 miles from ground zero, the overpressure will have decreased to roughly 1 pound per square inch. Most of the material damage caused by an air burst nuclear bomb is due mainly—directly or indirectly—to the blast (or shock) wave. The majority of structures will suffer some damage from air blast when the overpressure in the blast wave is about one-half pound per square inch or more.

3.38 The distance from ground zero at which the Mach stem commences, and to which an overpressure of one-half pound per square inch will extend, depends on the yield or size of the explosion and on the height of the burst. As the height of the burst for an explosion of given energy is decreased, Mach reflection commences nearer to ground zero, and the overpressure at the surface near ground zero becomes larger. If the bomb is exploded at a greater height, the Mach fusion commences farther away, and the overpressure at the surface is reduced. An actual contact surface burst leads to the highest possible overpressures near ground zero, but no Mach effect occurs, since there is no reflected wave.

3.39 In the nuclear explosions over Hiroshima and Nagasaki during World War II, the height of burst was about 1,850 feet. It was estimated, and has since been confirmed by nuclear test explosions, that a 20-kiloton bomb burst at this height would cause maximum blast damage to structures on the ground for the particular targets concerned. Actually, there is no single optimum height of burst, with regard to blast effects, for any specified explosion energy yield, because the chosen height of burst will be determined by the nature of the target. As a rule, strong (or hard) targets will require low air or surface bursts. For weaker targets, which are destroyed or damaged at relatively low overpressures or dynamic pressures (the dynamic pressure is a function of the wind velocity and air density behind the blast front), the height of burst may be raised in order to increase the area of damage, since the distance at which low overpressure would result would be extended because of the Mach effect.

POSITIVE AND NEGATIVE PHASES

3.40 As the blast wave travels in the air away from its source, the overpressures at the front steadily decrease, and the pressure behind the front falls off in a regular manner. After a short time, when the blast front has traveled a certain distance from the fireball, the pressure behind the front drops below that of the normal atmosphere and a so-called NEGATIVE PHASE of the blast wave forms. *In this region the air pressure is below that of the original (or ambient) atmosphere.*

3.41 During the negative overpressure (or suction) phase, a partial vacuum is produced and the air is sucked in, instead of being pushed away, as it is when the overpressure is positive. In the positive (or compression) phase, the wind associated with the blast wave blows away from the explosion, and in the negative phase its direction is reversed.

3.42 This wind is often referred to as a "transient" wind because its velocity decreases rapidly with time. During the positive phase, these winds may have peak velocities of several hundred miles per hour at points near ground zero, and even at more than 6 miles from the explosion of a 1-megaton nuclear explosion, the peak velocity may be greater than 70 miles per hour. It is evident that such strong winds can contribute greatly to the blast damage following an air burst. The peak negative values of overpressure are small compared with the peak positive overpressures. Thus, it is during the compression phase that most of the destructive action of blast from an air burst will be experienced. However, the winds associated with the negative phase can be quite damaging to weakened structures.

3.43 From the practical viewpoint, it is of interest to visualize the changes of overpressure in the blast wave with time at a fixed location. The variation of overpressure with time that would be observed at such a location in the few seconds following the detonation is shown in Figure 3.43a. The corresponding general effects to be expected on a light structure, a tree, and a small animal are indicated at the

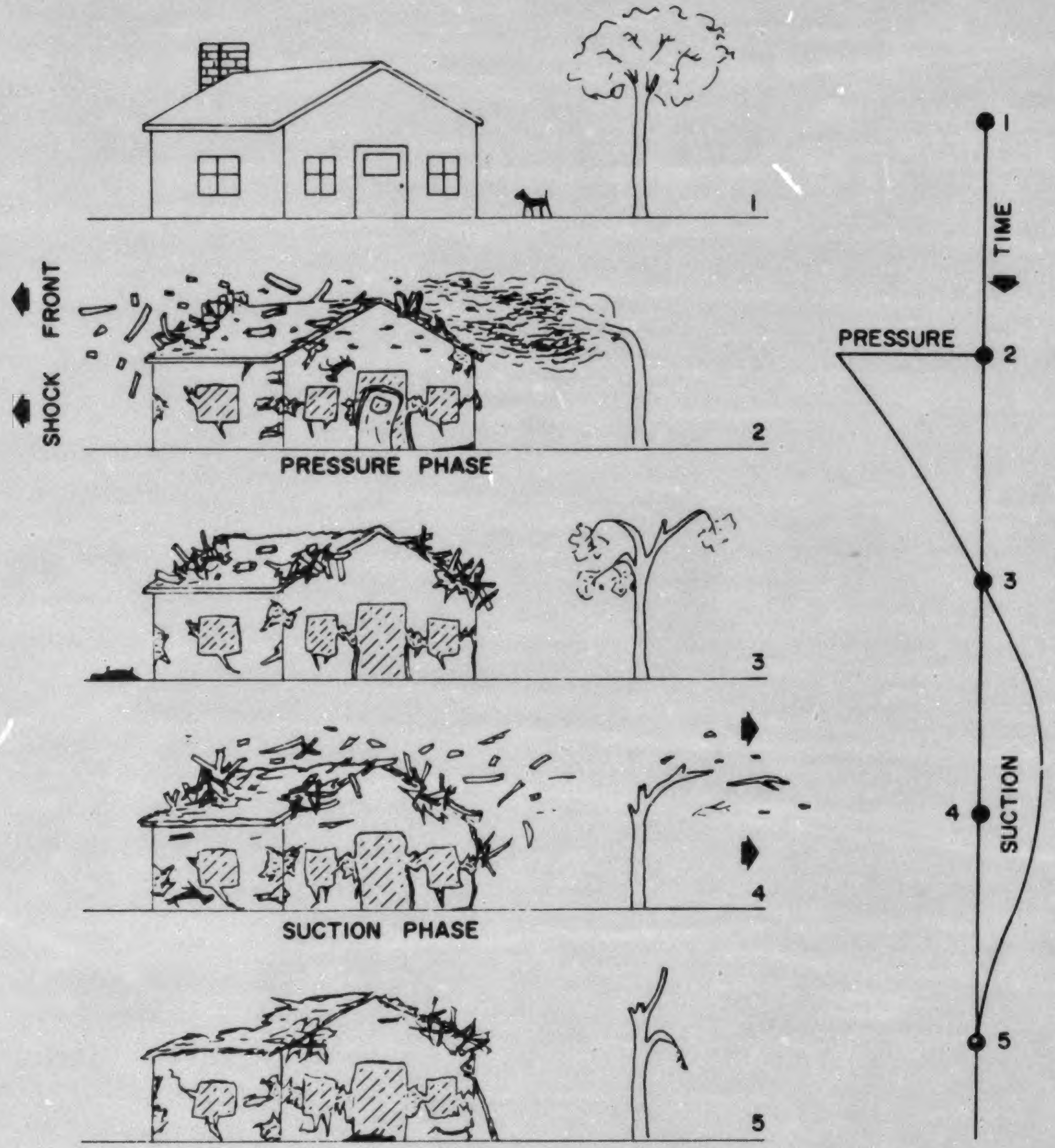

1
SHOCK FRONT
PRESSURE
2
PRESSURE PHASE
3
4
SUCTION PHASE
5
TIME
SUCTION

FIGURE 3.43a.—Variation of pressure with time at a fixed location and effect of blast wave passing over a structure.

left of the figure. Additional data is presented in Figures 3.43b and 3.43c.

BLAST CASUALTIES

3.44 There are four different kinds of injuries caused by the blast of an atomic weapon. Victims may be injured in one or all of these four ways, depending upon many factors, including the degree of protection, closeness to ground zero, size of bomb, height of detonation, etc.

3.45 The four kinds of blast injuries are:

(1) primary blast injuries, caused by the high pressures of the blast wave;

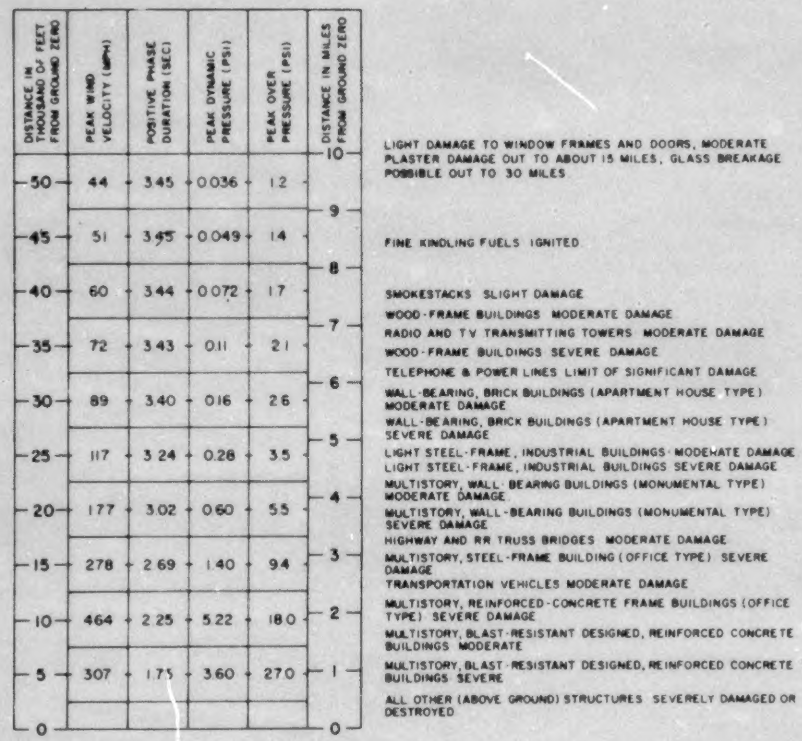


FIGURE 3.43b.—Damage ranges for a 1-MT typical air burst.

(2) those from the impact of missiles thrown about by the force of the blast;

(3) result of being thrown about by the blast; and

(4) miscellaneous injuries, such as exposure to ground shock; dust inhalation; fires caused by the explosion, etc.

3.46 Seventy percent of those who survived the nuclear bombing in Japan suffered from blast injury. Since many of the survivors were also injured in other ways (burns and/or radiation—both to be discussed later) we cannot say that this is the percentage of injuries caused by blast. Nevertheless, blast *was* one of the major causes of injury and, certainly, a major cause of death.

THE BOMB (RADIOACTIVE) CLOUD

3.47 In addition to the transient winds associated with the passage of the blast front, a strong updraft with inflowing winds, called "afterwinds", is produced in the immediate vicinity of the detonation due to the rising fireball. These afterwinds cause varying amounts of dirt and debris to be sucked up from the earth's surface into the atomic cloud. (Refer to Figure 3.28e.)

3.48 At first, the rising mass of bomb residue carries the particles upward, but after a time, the particles begin to spread out and fall slowly under the influence of wind and gravity. This is FALLOUT.

THERMAL RADIATION

3.49 Immediately after the fireball is formed, it starts to emit thermal radiation. Because of the very high temperatures of the fireball, this radiation consists of visible light rays, invisible ultraviolet rays of shorter wave length, and invisible infrared rays of longer wave length. These rays all travel with the speed of light. Due to certain physical phenomena associated with the absorption of the thermal radiation by the air in front of the fireball, the surface temperature of the fireball undergoes a curious change. The temperature

STRUCTURE TYPE	DAMAGE	EXPLOSION YIELD (Distance in miles)		
		100 KT	1 MT	10 MT
WOOD-FRAME BUILDING, RESIDENTIAL TYPE	MODERATE	3.2	6.6	14
	SEVERE	2.4	5.5	12
WALL-BEARING, MASONRY BUILDING, APARTMENT HOUSE TYPE	MODERATE	2.4	4.7	10
	SEVERE	1.7	3.5	8.7
MULTISTORY, WALL-BEARING BUILDING, MONUMENTAL TYPE	MODERATE	1.6	3.5	7.4
	SEVERE	1.3	2.8	6.1
REINFORCED CONCRETE (NOT EARTHQUAKE RESISTANT) BUILDING, CONCRETE WALL, SMALL WINDOW AREA	MODERATE	1.5	3.4	7.2
	SEVERE	1.1	2.5	5.9

FOR A SURFACE BURST THE RESPECTIVE DISTANCES ARE THREE QUARTERS OF THOSE FOR AN AIR BURST OF THE SAME YIELD.

FIGURE 3.43c.—Maximum ranges from ground zero for structural damge from air bursts.

decreases rapidly for a fraction of a second. Then, the surface temperature increases again for a somewhat longer time, after which it falls continuously. In other words, there are effectively two surface-temperature pulses: the first is of very short duration, whereas the second lasts for a much longer time. This behavior is quite standard with all size weapons, although the duration times of the two pulses increase with the energy yield of the explosion. After about 3 seconds from the detonation of a 20 KT bomb, the fireball, although still very hot, has cooled to such an extent that the thermal radiation is no longer important, whereas amounts of thermal radiation still continue to be emitted from the fireball at 11 seconds after a 1-megaton explosion.

3.50 Corresponding to the two temperature pulses, there are two pulses of emission of thermal radiation from the fireball (Figure 3.50). In the first pulse, which lasts about a tenth of a second for a 1-megaton explosion, the temperatures are mostly very high. As a result, much of the radiation emitted in this pulse is in the ultraviolet region. Moderately large doses of ultraviolet radiation can produce painful blisters, in milder form these effects are familiar as sunburn. However, in most circumstances, the first pulse of thermal radiation is not a significant hazard, with regard to skin burns, for several reasons. In the first place, only about 1 percent of the thermal radiation appears in the initial pulse because of its short duration. Second, the ultraviolet rays are readily absorbed in the atmosphere, so that the dose delivered at a distance from the explosion may be comparatively small. Further, it appears that the ultraviolet radiation from the first pulse could cause significant effect on the human skin only within ranges where people would be killed outright by the blast and at which other radiation effects are much more serious.

3.51 The situation with regard to the second pulse is, however, quite different. This pulse may last for several seconds and carries about 99 percent of the total thermal radiation energy from the bomb. Since the temperatures are lower than in the first pulse, most of the rays reaching the earth consist of visible and infrared light. It is this radiation which is the main cause of skin burns of various degrees suffered by exposed individuals out to 12 miles or more from the explosion of a 1-megaton bomb, on a fairly clear day. The warmth may be felt at a distance of 75 miles. For air bursts of higher energy yields, the corresponding distances, will, of course, be greater. Generally, thermal radiation is capable of causing skin burns on exposed individuals at such distances from the nuclear explosion that the effects of blast and of the initial nuclear radiation are not significant.

THERMAL RADIATION CASUALTIES

3.52 It is convenient to divide thermal burns due to a nuclear explosion into two classes, namely (1) primary burns, and (2) secondary burns. As in the case of blast injuries, the terms primary and secondary refer to the manner in which the burns are inflicted. Those in the first class are a direct result of thermal radiation from the bomb, while those in the second group arise indirectly from fires caused by the explosion. From the medical point of view, a burn is a burn, whether received as a flash burn from the initial thermal burst or, at a later time, from the burning environment.

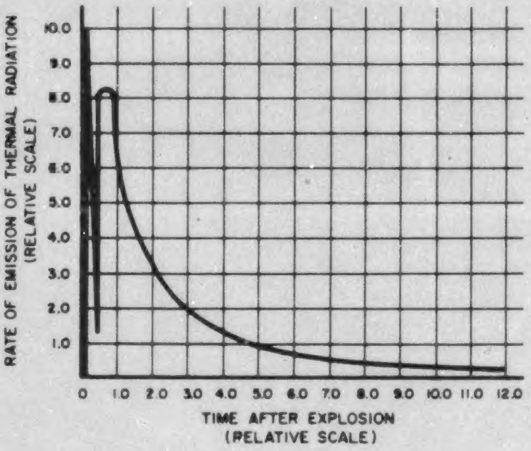


FIGURE 3.50.—Emission of thermal radiation in two pulses.

3.53 Experiments in the laboratory and in the field have established criteria for assessing the degree of thermal damage to be expected for doses of thermal radiation delivered to human tissue within specified time limits. Medical diagnosis usually recognizes three grades of thermal injury: first, second and third degree injury in ascending order of severity. A first-degree burn corresponds to a moderate sunburn or erythema. Such damage, while quite painful, is reparable with time and requires no special treatment beyond the relief of pain. The second-degree burn involves the skin thickness down to and including portions of the dermis. A characteristic feature of second-degree burns is the formation of blisters. The second-degree burn is extremely painful but also reparable with time. Infection usually occurs since the protective barrier of the epidermis has been pierced, leaving the tissues open to infective pathogens. Given time and opportunity to combat infection, the majority of second-degree wounds heal without undue aftereffects though permanent pigmentation changes may persist. The third-degree burn involves complete destruction of the whole skin thickness. Except for very small area burns these are *not* reparable with time but require skin grafting in all cases. Infection is invariably present. Paradoxically, the third-degree burn is not as painful as the second-degree burn because the nerve endings have been destroyed; yet third-degree burns to more than 25 percent of the human body area might represent a fatal injury.

3.54 The treatment of severe thermal injury on areas in excess of 25 percent of the whole body represents a grave medical problem even in a modern hospital and under the best of circumstances. For mass burn casualties under field conditions the situation takes on overwhelming proportions. An unwarned urban population caught out of doors during a nuclear attack would suffer almost complete annihilation from blast and thermal energy out to a radius of many miles from ground zero. While it is feasible to avoid the prompt thermal flash by taking cover, it is not so evident how to avoid the secondary effects of the burning environment which develops soon after the burst. It is probable that burns from secondary fires engendered by the bomb would represent a major proportion of the casualties even for a population which had received warning of imminent attack. (From 65–85% of the atom bomb survivors in Japan were burned to some degree.) Figure 3.54 shows the ranges in miles at which people in the open would suffer various degrees of skin burn from surface burst weapons of different power.

THERMAL EFFECTS OF WEAPONS OF DIFFERENT YIELDS

3.55 A 10MT weapon radiates 500 times as much heat as a 20KT bomb. According to the "inverse square" law a 10MT weapon should produce the same amount of heat as the 20KT weapon at a distance 22 times greater (since $\sqrt{500} = 22$ approx.). But the heat from the larger bomb is spread over a much longer period, 20 seconds compared with a $1^1/_2$ second flash from the 20KT bomb, so that more of the heat is dissipated.

RADII IN MILES

WEAPON POWER	20 KT	100 KT	1 MT	2 MT	5 MT	10 M
FIRST DEGREE BURN	1.5	3.0	8.0	11.0	15.0	21.0
SECOND DEGREE BURN	1.0	2.0	5.5	7.5	11.0	15.0
THIRD DEGREE BURN	0.875	1.5	4.75	6.25	9.5	13.0

FIGURE 3.54.—Range of effects from surface bursts on people exposed in open.

3.56 Nuclear weapons of 10–100KT deliver at least 60 percent of the total thermal radiation from the second radiation pulse in less than 0.5 second. Weapons in the 1–10MT range, while producing more thermal energy over a greater radius from the burst than weapons of 100KT or less, deliver this thermal energy at a much slower rate than the small weapons. Thus, for equal thermal doses incident on tissue, the small weapons are more effective in producing thermal injury because the large weapons require anywhere from 5 to 15 seconds to deliver 60 percent of the thermal dose. For example, it requires 7–9 cal./cm.^{2} to produce second-degree burns from a 10MT weapon. This illustrates a most important factor: *The larger the weapon, the greater the time available for evasive action.* However, evasive tactics must be exercised before 60 percent of the total energy has been delivered. For personnel well indoctrinated in evasive tactics, this could mean the difference between a moderate sunburn and severe thermal injury. Figure 3.56 shows thermal energies required to cause first, second and third-degree burns from different yield weapons.

3.57 Temporary or permanent blindness could be caused by the thermal radia-

EXPLOSIVE YIELD	1 KT	20 KT	100 KT	1 MT	10 MT	20 MT
FIRST DEGREE BURN	2.0	2.5	2.7	3.2	3.7	3.8
SECOND DEGREE BURN	4.1	4.9	5.4	6.2	7.2	7.5
THIRD DEGREE BURN	6.0	7.3	8.1	9.4	10.8	11.4

FIGURE 3.56.—Approximate thermal energies in Cal./cm.^{2} required to cause skin burns in air or surface burst.

tion if a person is looking in the general direction of the fireball at the precise moment of detonation. The lens of the eye focuses heat as well as light rays on the retina of the eye. Thus in addition to temporary or "flash" blindness of a few seconds or minutes duration from the intense light, actual burns of the retina could occur from undue amounts of thermal radiation entering the eye. Neither flash blindness nor retinal damage constitute major hazards during daylight because of natural restriction of the diameter of the pupil which limits the amount of light entering the eye; furthermore the blink reflex, one hundred and fifty thousandths of a second, protects the eye from undue amounts of radiation, except in those cases where the thermal pulse is delivered within extremely short times. This is the case for low-yield weapons and can also be true for high altitude bursts.

3.58 It is an interesting fact that among the survivors in Hiroshima and Nagasaki, eye injuries directly attributable to thermal radiation appeared to be relatively unimportant. There were many cases of temporary blindness, occasionally lasting up to 2 or 3 hours, but more severe eye injuries were not common.

3.59 The eye injury known as keratitis (an inflammation of the cornea) occurred in some instances. The symptoms, including pain caused by light, foreign-body sensation, lachrymation, and redness, lasted for periods ranging from a few hours to several days.

EFFECT OF SMOKE, FOG AND SHIELDING

3.60 In the event of an air burst occurring above a layer of dense cloud, smoke, or fog, an appreciable portion of the thermal radiation will be scattered upward from the top of the layer. This scattered radiation may be regarded as lost, as far as a point on the ground is concerned. In addition, most of the radiation which penetrates the layer will be scattered and very little will reach the given point by direct transmission. These two effects (smoke or fog) will result in a substantial decrease in the amount of thermal energy reaching a ground target.

3.61 It is important to understand that the decrease in thermal radiation by fog and smoke will be realized only if the burst point is above or, to a lesser extent, within the fog (or similar) layer. If the explosion should occur in moderately clear air beneath a layer of cloud, or fog, some of the radiation which would normally proceed outward into space will be scattered back to earth. As a result, the thermal energy received will actually be greater than for the same atmospheric transmission condition without a cloud or fog cover.

3.62 Unless scattered, thermal radiation from a nuclear explosion, like ordinary light in general, travels in straight lines from its source, the fireball. *Any solid object, opaque material, such as a wall, a hill, or a tree, between a given object and the fireball, will act as a shield and provide protection from thermal radiation.* Transparent materials, on the other hand, such as glass or plastics, allow thermal radiation to pass through, only slightly absorbed.

3.63 In the case of an explosion in the kiloton range, it would be necessary to take evasive action within a small fraction of a second if an appreciable decrease in thermal injury is to be realized. The time appears to be too short for such action to be possible. On the other hand, for explosions in the megaton range, evasive action taken within a second or two of the appearance of the ball of fire could reduce the severity of injury due to thermal radiation in many cases and may even prevent injury in others.

NUCLEAR RADIATION

3.64 It was stated in paragraph 3.4 that one of the unique features of a nuclear explosion is that it is accompanied by the emission of various nuclear radiations. These radiations, which are quite different from thermal radiation, consist of gamma rays, neutrons, beta particles, and a small proportion of alpha particles. Essentially all the neutrons and part of the gamma rays are emitted in the actual fission process. That is, these radiations are produced simultaneously with the nuclear explosion, whereas the beta particles and the remainder of the gamma rays are liberated from fission products in the course of their radioactive decay. The alpha particles result from the normal radioactive decay of the uranium or plutonium that has escaped fission in the bomb.

3.65 Because of the nature of the phenomena associated with a nuclear explosion, either in the air or near the surface, it is convenient for practical purposes to consider the nuclear radiation as being divided into two categories; namely, initial and residual.

INITIAL NUCLEAR RADIATION

3.66 The initial nuclear radiation is generally defined as that emitted from the fireball and the atomic cloud within the first minute after the detonation. It includes neutrons and gamma rays given off almost instantaneously, as well as the gamma rays emitted by the radioactive fission products in the rising cloud. It should be noted that, although alpha and beta particles are present in the initial radiation, they have not been considered. This is because they are so easily absorbed that they will not reach more than a few yards, at most, from the atomic cloud.

3.67 The somewhat arbitrary time period of 1 minute for the duration of the initial nuclear radiation was originally based upon the following considerations. As a consequence of absorption by the air, the effective range of the fission gamma rays and those from the fission products from a 20-kiloton explosion is very roughly 2 miles. In other words, gamma rays originating from such a source at an altitude of over 2 miles can be ignored as far as their effect at the earth's surface is concerned. Thus, when the atomic cloud has reached a height of 2 miles, the effects of the initial nuclear radiation are no longer significant. Since it takes roughly a minute for the cloud to rise this distance, the *initial nuclear radiation is defined as that emitted in the first minute after the explosion.*

3.68 The foregoing discussion is based on the characteristics of a 20-kiloton nuclear bomb. For a bomb of higher energy, the maximum distance over which the gamma rays are effective will be greater than given above. However, at the same time, there is an increase in the rate at which the cloud rises. Similarly for a bomb of lower energy, the effective distance is less, but so is the rate of ascent of the cloud. The period over which the initial nuclear radiation extends may consequently be taken to be approximately the same; namely, 1 minute irrespective of the energy release of the bomb.

3.69 Neutrons produced directly in the thermonuclear reactions mentioned in paragraph 3.18 are of special significance. Some of the neutrons will escape but others will be captured by the various nuclei present in the exploding bomb. These neutrons absorbed by fissionable species may lead to the liberation of more neutrons as well as to the emission of gamma rays, just as described above for an ordinary fission bomb. In addition, the capture of neutrons in non-fission reactions is usually accompanied by gamma rays. It is seen, therefore, that the initial radiation from a bomb in which both fission and fusion (thermonuclear) processes occur, consists essentially of neutrons and gamma rays. The relative proportions of these two radiations may be somewhat different than for a bomb in which all the energy released is due to fission, but for present purposes, this difference may be disregarded. The range of lethal effects from initial nuclear radiation are well within the areas of severe blast and thermal damage.

RESIDUAL NUCLEAR RADIATION

3.70 The radiation which is emitted 1 minute after a nuclear explosion is defined as residual nuclear radiation. This radiation arises mainly from the bomb residue; that is, from the fission products and, to a lesser extent, from the uranium and plutonium which have escaped fission. In addition, the residue will usually contain some radioactive isotopes formed as a result of neutron capture by bomb materials.

Another source of residual nuclear radiation is the activity induced by neutrons captured in various elements present in the earth, in the sea, or in the substances which may be in the explosion environment.

3.71 With surface and, especially, subsurface explosions, the demarcation between initial and residual nuclear radiation is not as definite. Some of the radiation from the bomb residue will be within the range of the earth's surface at all times so that the initial and residual categories merge continuously into one another. For very deep underground and underwater bursts, the initial gamma rays and neutrons produced in the fission process may be ignored. Essentially the only nuclear radiation of importance is that arising from the bomb residue. It can consequently be treated as consisting exclusively of the residual radiation. In an air and surface burst, however, both initial and residual nuclear radiation must be taken into consideration.

3.72 One additional important consideration of nuclear radiation is that the residual nuclear radiation *can, under some conditions, represent a serious hazard at great distances from a nuclear explosion, well beyond the range of blast, shock, thermal radiation, and initial nuclear radiation.* This phenomenon—**FALLOUT**—will be discussed at length in later chapters.

CHARACTERISTICS OF A SURFACE BURST

3.73 In a surface burst, the ball of fire in its rapid initial growth will touch the surface of the earth. Because of the intense heat, a considerable amount of rock, soil, and other material located in the area will be vaporized and taken into the ball of fire. It has been estimated that if only 5 percent of a 1-megaton bomb's energy is spent in this manner, something like 20,000 tons of vaporized soil material will be added to the normal constituents of the fireball. In addition, the high winds at the earth's surface will cause large amounts of dirt, dust, and other particles to be sucked up as the ball of fire rises (See Figure 3.28e).

3.74 *An important difference between a surface burst and an air burst is that in the surface burst the atomic cloud is much more heavily loaded with debris* (and so produces much more **FALLOUT**). This will consist of particles ranging in size from the very small ones produced by condensation as the fireball cools, to the much larger particles which have been raised by the surface winds. The exact composition of the cloud will, of course, depend on the nature of the terrain and the extent of contact with the fireball.

3.75 For a surface burst associated with a moderate amount of debris, as was the case in several test explosions in which the bombs were detonated near the ground, the rate of rise of the cloud is much the same as given earlier for an air burst. The atomic cloud reaches a height of several miles before spreading out into a mushroom shape.

3.76 The vaporization of dirt and other material when the fireball has touched the earth's surface, and the removal of material by the blast wave and winds accompanying the explosion, result in the formation of a crater. The size of the crater will vary with the height above the surface at which the bomb is exploded and with the character of the soil, as well as the energy of the bomb. It is believed that for a 1-megaton bomb there would be no appreciable crater formation unless detonation occurs at an altitude of 450 feet or less.

3.77 If a nuclear bomb is exploded near the surface of the water, large amounts of water will be vaporized and carried up into the atomic cloud. For example, if it is supposed, as above (paragraph 3.73), that 5 percent of the energy of the 1-megaton bomb is expended in this manner, about 100,000 tons of water will be converted into vapor. At high altitudes this will condense to form water droplets similar to those in an ordinary atmospheric cloud.

AIR BLAST AND GROUND SHOCK

3.78 The overall blast effect due to the air shock from a surface burst will be less than that from an air burst for weapons of equivalent yield. For one thing, part of the energy of the bomb is used up in vaporizing materials on the surface and in forming a crater. In addition, up to 15 percent of the energy may go into ground shock. The main point, however, is that because the bomb explodes close to the earth's surface, the overpressure near ground zero will be much greater than for an air burst, but it will fall off more rapidly with increasing distance from ground zero.

3.79 As a result, energy will be wasted on targets close to ground zero which could have been destroyed by much lower overpressures. At the same time, the overpressures at some distance away will be too low to cause any considerable damage. In other words, there will be an "overdestruction" of nearby surface targets and an "under-destruction" of those further away. *The energy that has gone to produce ground shock may contribute, however, to the destruction of underground targets protected from the air blast such as missile launching sites.* Figure 3.43c, (and its legend), will provide additional specific information on surface bursts.

THERMAL RADIATION

3.80 The general characteristics of the thermal radiation from a nuclear detonation at the surface will be essentially the same as for an air burst, described previously. As stated earlier, if evasive action can be taken within a second or so, part of the heat radiation may be avoided.

INITIAL NUCLEAR RADIATION

3.81 The initial nuclear radiation from a surface burst will be similar to that in an air burst. However, if the low level nuclear explosion occurred in a more or less built-up area, the structures through which it passed would serve to reduce, even though they would not completely shield, the gamma radiation. For practical purposes, however, it would be advisable to treat these two types of burst as the same as far as initial nuclear radiation is concerned.

RESIDUAL NUCLEAR RADIATION

3.82 With respect to residual radioactivity, a nuclear explosion at a low level would produce effects somewhat similar to a subsurface burst. That is, a considerable amount of dirt and other debris or water, would be hurled into the air, and upon descending, it might produce a base surge (highly radioactive cloud of dust or vapor) which will be contaminated partly from the condensation on the ground of the nuclear reaction products from the ball of fire, partly from the fallout of heavier pieces, and partly from radioactivity induced by neutrons.

CHARACTERISTICS OF A SUBSURFACE BURST

3.83 When a nuclear bomb is exploded under the ground, a ball of fire is formed consisting of extremely hot gases at high pressures, including vaporized earth and bomb residue. If the detonation occurs at not too great a depth, the fireball may be seen as it breaks through the surface, before it is obscured by clouds of dirt, and dust. As the gases are released, they carry up with them into the air large quantities

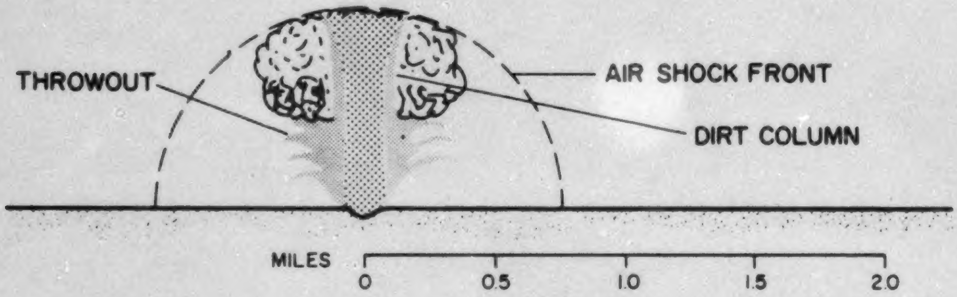
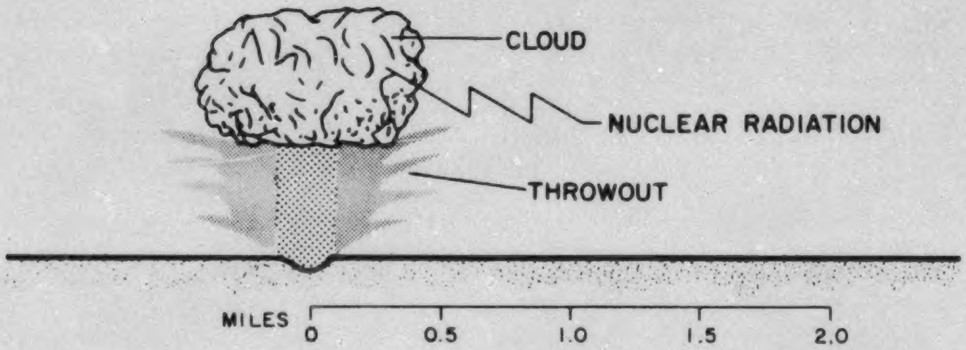


FIGURE 3.83a.—Chronological development of a 100-KT shallow underground burst: 2.0 seconds after detonation.


CLOUD
NUCLEAR RADIATION
THROWOUT
MILES
0
0.5
1.0
1.5
2.0

IGURE 3.83b.—Chronological development of a 100–KT shallow underground burst: 9.0 seconds after detonation.

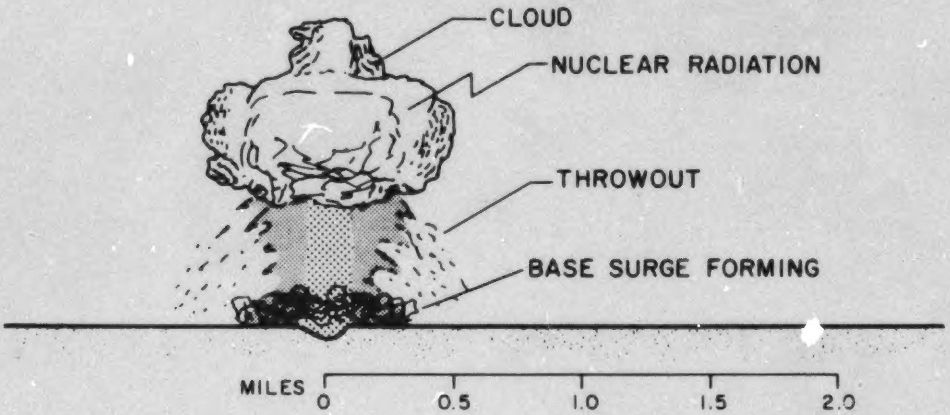

CLOUD
NUCLEAR RADIATION
THROWOUT
BASE SURGE FORMING
MILES
0
0.5
1.0
1.5
2.0

FIGURE 3.83c.—Chronological development of a 100–KT shallow underground burst: 45 seconds after detonation.

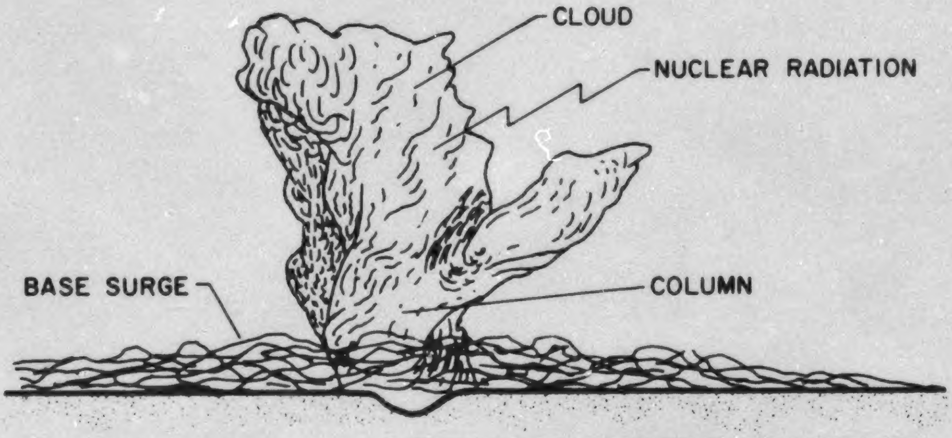

CLOUD
NUCLEAR RADIATION
BASE SURGE
COLUMN
MILES
0
0.5
1.0
1.5
2.0

FIGURE 3.83d.—Chronological development of a 100–KT shallow underground burst: 4.5 minutes after detonation.

of earth, rock, and debris in the form of a cylindrical column. The chronological development of some of the phenomena associated with an underground explosion, having an energy yield of 100 kilotons, is represented by Figures 3.83a to 3.83d.

3.84 It is estimated from tests made in Nevada that, if a 1-megaton bomb were dropped from the air and penetrated underground in sandy soil to a depth of 50 feet before exploding, the resulting crater would be about 300 feet deep and nearly 1,400 feet across. This means that approximately 10 million tons of soil and rock would be hurled upward from the earth's surface. The volume of the crater and the mass of material thrown up by the force of the explosion will increase roughly in proportion to the energy of the bomb. As they descend to earth, the finer particles of soil may initiate a base surge as shown in Figure 3.83d.

AIR BLAST AND GROUND SHOCK

3.85 The rapid expansion of the bubble of hot, high-pressure gases formed in the underground burst initiates a shock wave in the earth. Its effects are somewhat similar to those of an earthquake of moderate intensity, except that the disturbance originates fairly near the surface instead of at a great depth. The difference in depth of origin means that the pressures in the underground shock wave caused by a nuclear bomb probably fall off more rapidly with distance than do those due to earthquake waves.

3.86 Part of the energy from an underground nuclear explosion appears as a blast wave in the air. The fraction of the energy imparted to the air in the form of blast depends primarily upon the depth of the burst. The greater the penetration of the bomb before detonation occurs, the smaller is the proportion of the shock energy that escapes into the air.

THERMAL AND NUCLEAR RADIATION

3.87 Essentially all the thermal radiation emitted by the ball of fire while it is still submerged is absorbed by the surrounding earth. When the hot gases reach the surface and expand, the cooling is so rapid that the temperature drops almost immediately to a point where there is no further appreciable emission of thermal radiation. It follows, therefore, that in an underground nuclear explosion the thermal radiation can be ignored as far as its effects on personnel and as a source of fire are concerned.

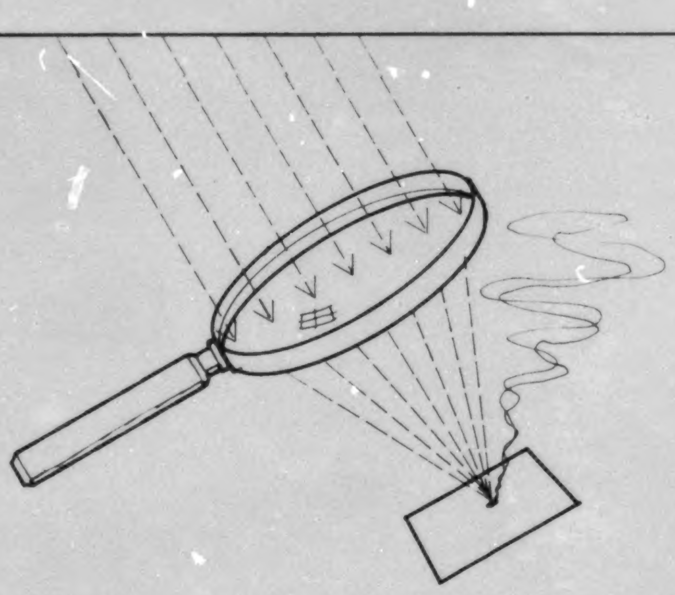
3.88 It is probable, to, that most of the neutrons and gamma rays liberated within a short time of the initiation of the explosion will also be absorbed by the earth. But, when the fireball reaches the surface and the gases are expelled, the gamma rays (and beta particles) from the fission products will represent a form of initial nuclear radiation. In addition, the radiation from the fission (and neutron-induced radioactive) products present in the cloud stem, radioactive cloud, and base surge, all three of which are formed within a few seconds of the burst, will contribute to the initial effects.

3.89 However, the fallout from the cloud and the base surge are also responsible for the residual nuclear radiation. For a subsurface burst, it is thus less meaningful to make a sharp distinction between initial and residual radiation, such as is done in the case of an air burst. The initial nuclear radiation merges continuously into those which are produced over a period of time following the nuclear explosion.

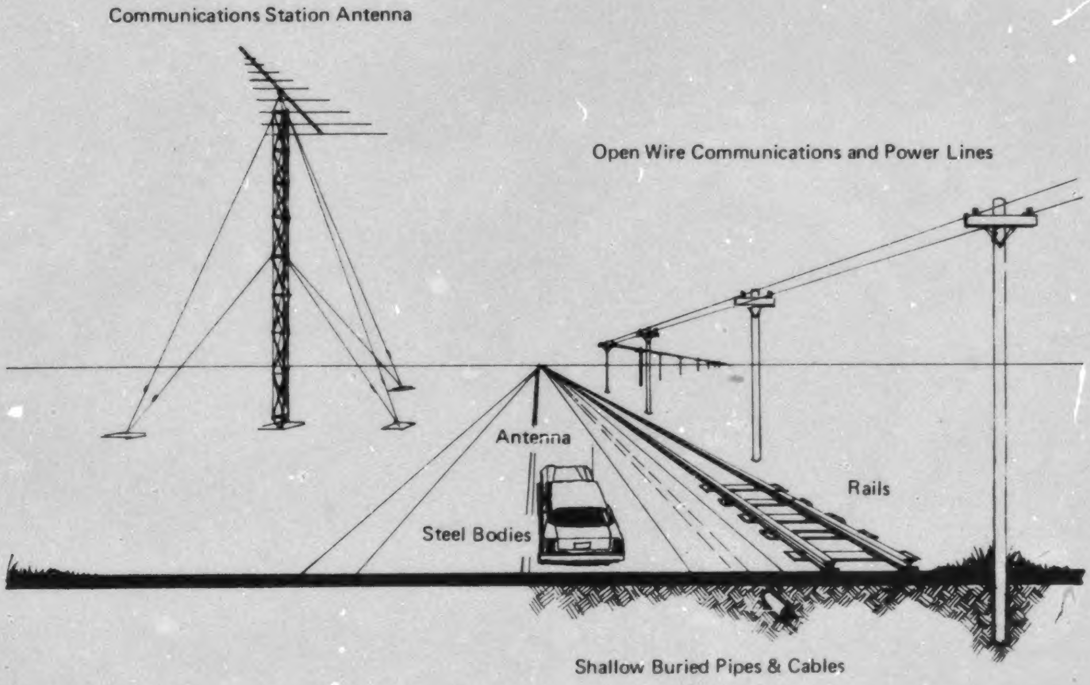
HIGH ALTITUDE BURSTS

3.90 For nuclear detonations at heights up to about 100,000 feet the density of air is such that the distribution of the explosion energy remains almost unchanged, approximating that described for an air burst, e.g., about 45 to 55 percent (of the fission energy) appears as blast and shock and 30 to 40 percent is received as thermal radiation.

3.91 At greater altitudes, this distribution begins to change noticeably with increasing height of burst, a smaller proportion of the energy appearing as blast. It is for this reason that the level of 100,000 feet has been chosen for distinguishing



A THERMAL ENERGY COLLECTOR


Communications Station Antenna
Open Wire Communications and Power Lines
Antenna
Rails
Steel Bodies
Shallow Buried Pipes & Cables

EMP ENERGY COLLECTORS

FIGURE 3.95.—EMP ENERGY COLLECTOR.

between air bursts and high-altitude bursts.

3.92 There is, of course, no sharp change in behavior at this elevation, and so the definition of a high-altitude burst as being at a height above 100,000 feet is somewhat arbitrary. Although there is a progressive decline in the blast energy with increasing height of burst above 100,000 feet, the proportion of the explosion energy received as effective thermal radiation on the ground does not at first change appreciably. This is due to the interaction of the primary thermal radiation with the surrounding air and its subsequent emission in a different spectral region. At still higher altitudes, the effective thermal radiation received on the ground decreases and is, in fact, less than at an equal distance from an air burst of the same total yield.

3.93 One aspect of a high-altitude burst that has received increased attention in recent years is the electromagnetic pulse (EMP). Its implications were first noted during an experimental high-altitude burst over Johnson Island in the Pacific Ocean in 1962 when street light failures and communications disruptions occurred on Oahu, 750 miles away. In an era of intercontinental ballistic missile systems, and defenses against those missiles, the possibility of a high-altitude burst in a nuclear attack becomes very real.

3.94 Put simply, the electromagnetic pulse is that portion of the electromagnetic spectrum (Figure 2.42) in the medium to low frequency range extending roughly from the frequencies used in radar and TV down to those used in electric power. Since most of the energy is radiated in the frequency bands commonly used for radio and TV communications, it is sometimes called "radio-flash." It is differentiated from the thermal radiation "pulse" that produce heat and light and the initial radiation "pulse" of gamma and X-rays.

3.95 There is concern about EMP because the energy in the pulse can be collected and concentrated, much as the sun's rays can be focused to produce a fire, as shown in the upper portion of Figure 3.95. The lower portion of the diagram shows some common EMP energy collectors. Sufficient energy can be collected by these means to cause damage to attached electrical and electronic equipment.

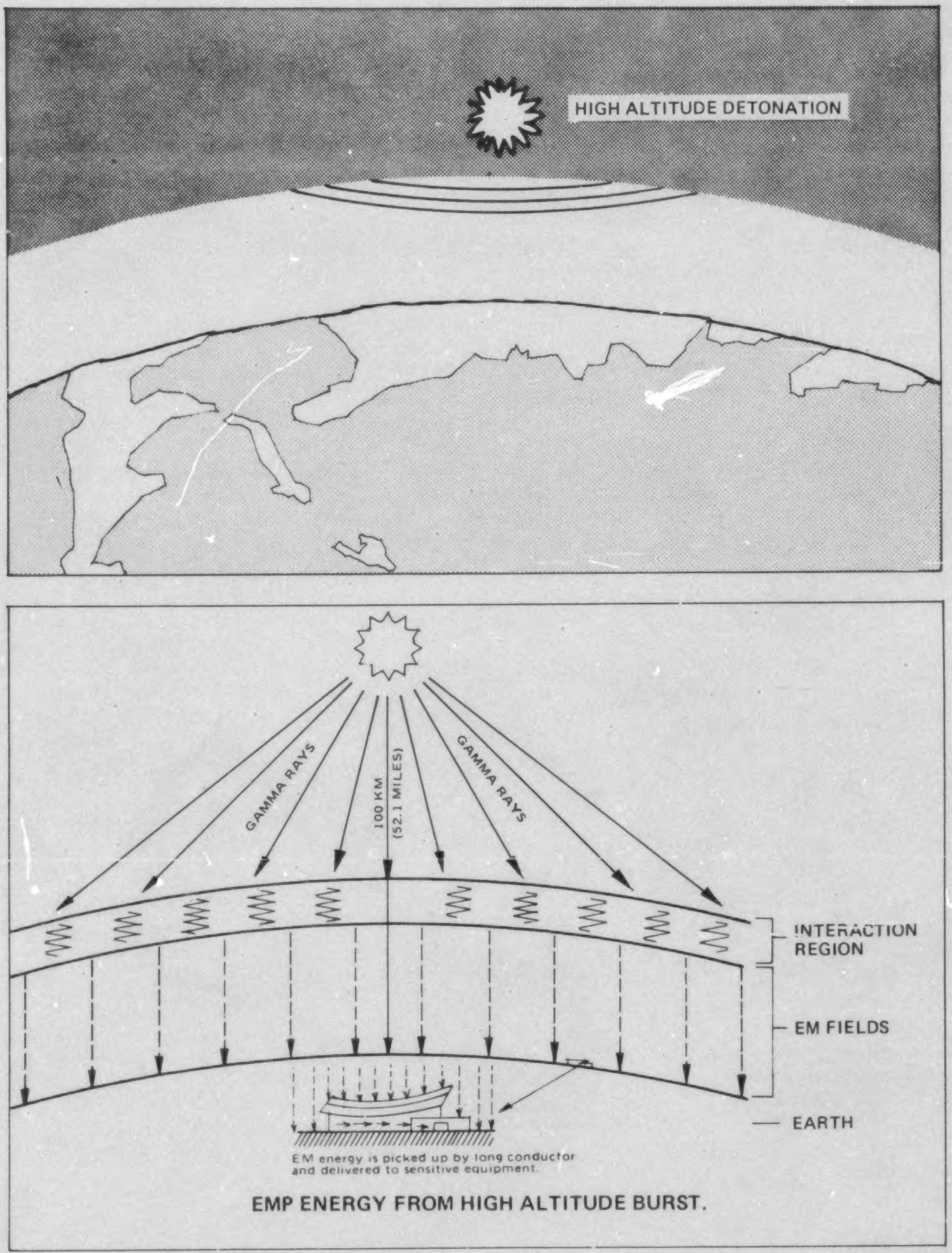
3.96 In a surface or near-surface burst the relevant EMP energies are generally well within the blast and thermal damage areas close to the point of nuclear detonation and thus cover a relatively small geographical area.

3.97 By contrast, if a nuclear weapon is detonated high above the earth's atmosphere, the X-rays and gamma rays emitted downward from the explosion will be absorbed in a big "pancake" layer of the atmosphere between $12^{1}/_{2}$ and 25 miles above the earth's surface, as shown in Figure 3.97. The gamma energy is converted into lower-frequency electromagnetic energy in this interaction region and propagated downward to the earth's surface as a very brief but powerful electromagnetic pulse. The strength of this pulse on the ground is much the same as in the moderate damage area of a surface burst. However, very large areas, otherwise undamaged, can be affected by the high altitude detonation, as the lateral extent of the "interaction region" is generally limited only by the curvature of the earth.

3.98 The extent of that damage can be seen by considering a typical high-altitude burst over Omaha, Nebraska as shown in Figure 3.98. Within the circle passing through Dallas, Texas the EMP hazard would be the greatest. The outer circle shows that there is potential damage from EMP effects over the whole area of the United States.

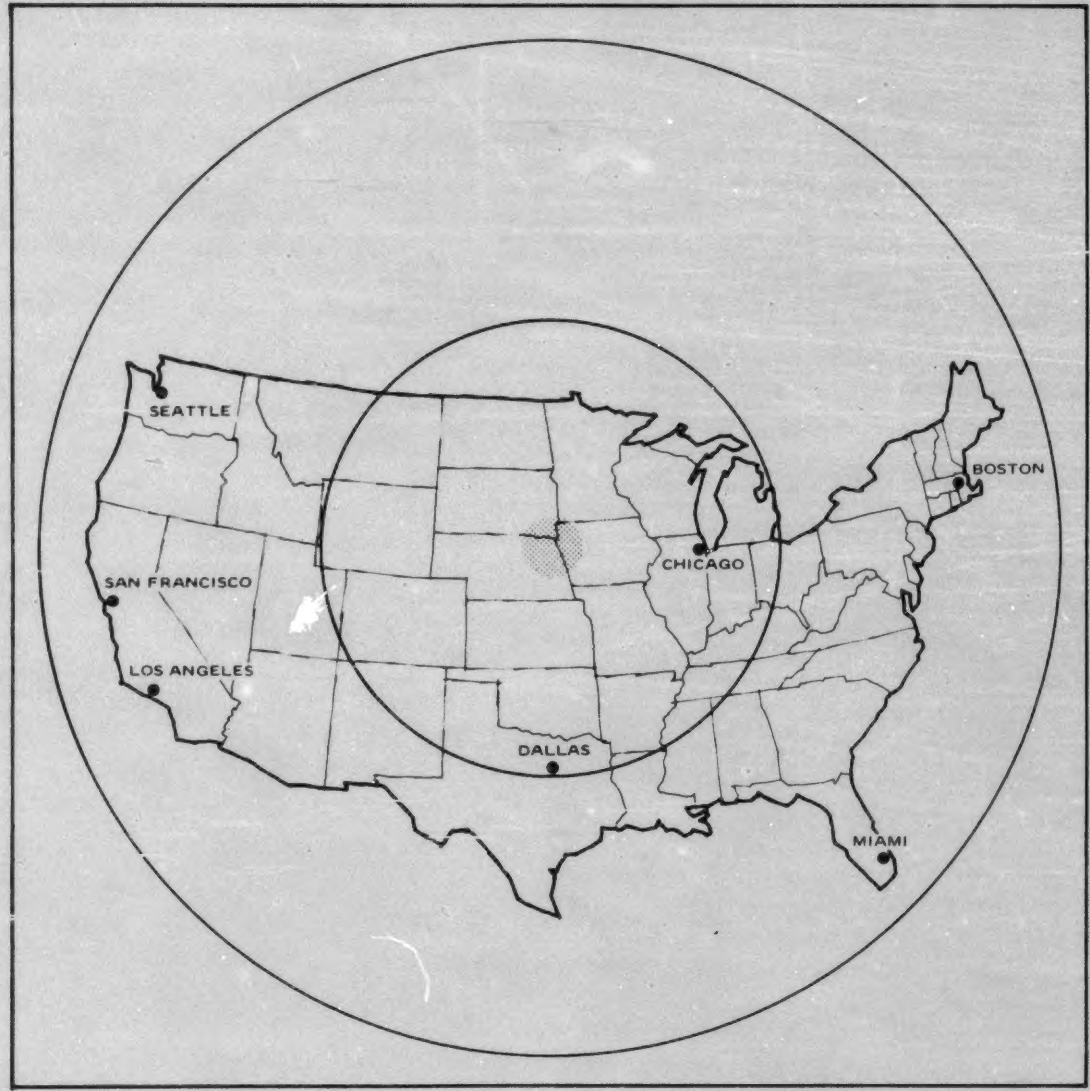
3.99 EMP can cause two kinds of damage. First, functional damage that would require replacement of a component or piece of equipment. Examples would be the burnout of a radio receiver "front end" or the blowing of a fuse. Second, operational upset of equipment such as opening of circuit breakers or erasure of a portion of the memory of a computer.

3.100 Experiments have shown that CD radiation detection equipment is not sus-


HIGH ALTITUDE DETONATION
GAMMA RAYS
100 KM
(52.1 MILES)
GAMMA RAYS
INTERACTION REGION
EM FIELDS
EARTH
EM energy is picked up by long conductor and delivered to sensitive equipment.
EMP ENERGY FROM HIGH ALTITUDE BURST.

From: **Survive**, November-December 1969

FIGURE 3.97.—EMP energy from high altitude burst.


SEATTLE
BOSTON
SAN FRANCISCO
CHICAGO
LOS ANGELES
DALLAS
MIAMI

EMP GROUND COVERAGE OF HIGH ALTITUDE BURSTS

Source: Defense Nuclear Agency

FIGURE 3.98.—EMP ground coverage of high altitude bursts

ceptible to direct damage nor are hand held Citizens Band walkie-talkies or FM radio receivers. The vulnerability of individual electrical or electronic equipment can vary greatly. Transistors and microwave diodes, for example, are relatively more vulnerable than vacuum tubes or electric motors.

3.101 The EMP threat and protective measures for civil preparedness related systems and equipment are available in technical publications of DCPA. Emergency operating centers, broadcast radio and TV, telephone and electric power systems and public safety radio are some of the areas of concern.

3.102 Listed below are seven anti-EMP actions that could be applicable to local civil preparedness operations.

1. Maintain a supply of spare parts.
2. Shift to emergency power at the earliest possible time.
3. Rely on telephone contact during threat period so long as it remains operational.
4. If radio communication is essential during threat period, use only one system at a time. Disconnect all other systems from antennas, cables, and power.
5. Disconnect radio base stations when not in use from antennas and power line.
6. Plan for mobile-to-mobile backup communications.
7. Design emergency operating plans so that operations will "degrade gracefully" if communications are lost.

SUMMARY OF EFFECTS OF VARIOUS TYPE BURSTS [4]

3.103 Some general conclusions can be offered in summary of the degree or severity of the particular effects of the various types of nuclear detonations. The various degrees are relative to each other for a given burst type, and are best interpreted in terms of the descriptions given below.

HIGH ALTITUDE BURST [5]

LIGHT: Very intense.

HEAT: Moderate, decreases with increasing burst altitude.

INITIAL NUCLEAR RADIATION: Negligible.

SHOCK: Negligible.

AIR BLAST: Small on the ground, decreasing with increasing burst altitude.

EARLY FALLOUT: None.

SUMMARY: The most significant effect will be flash blindness over a very large area; eye burns will occur in persons looking directly at the explosion. Other effects will be relatively unimportant.

AIR BURST

LIGHT: Fairly intense, but much less than for high-altitude burst.

HEAT: Intense out to considerable distances.

INITIAL NUCLEAR RADIATION: Intense, but generally hazardous out to shorter distance than heat.

SHOCK: Negligible except for very low air bursts.

AIR BLAST: Considerable out to distances similar to heat effects.

EARLY FALLOUT: Negligible.

SUMMARY: Blast will cause considerable structural damage; burns to exposed skin are possible over a large area and eye effects over a still larger area; initial nuclear radiation will be a hazard at closer distances; but the early fallout hazard will be negligible.

GROUND SURFACE BURST

LIGHT: Less than for an air burst, but still appreciable.

HEAT: Less than for an air burst, but significant.

INITIAL NUCLEAR RADIATION: Less than for an air burst.

SHOCK: Will cause damage within about three crater radii, but little beyond.

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[4] This summary is reprinted from THE EFFECTS OF NUCLEAR WEAPONS.

[5] As modified by 3.93–3.102.

AIR BLAST: Greater than for an air burst at close-in distances, but considerably less at farther distances.

EARLY FALLOUT: May be considerable (for a high-yield weapon) and extend over a large area.

SUMMARY: Except in the region close to ground zero, where destruction would be virtually complete, the effects of blast, thermal radiation, and initial nuclear radiation will be less extensive than for an air burst; however, early fallout may be a very serious hazard over a large area which is unaffected by blast, etc.

SHALLOW UNDERWATER BURST

LIGHT, HEAT, AND INITIAL NUCLEAR RADIATION: Less than for a ground surface burst, depending on the extent to which the fireball breaks through the surface.

SHOCK: Water shock will extend farther than a water surface burst.

AIR BLAST: Less than for surface burst, depending upon depth of burst.

EARLY FALLOUT: May be considerable, if the depth of burst is not too large, and in addition there may be a highly radioactive base surge.

SUMMARY: Light, heat, and initial nuclear radiation will be less than for a ground surface burst; early fallout can be significant, and at distances not too far from the explosion the base surge will be an important hazard.

WATER SURFACE BURST

LIGHT: Somewhat more intense than for a ground surface burst.

HEAT: Similar to ground surface burst.

INITIAL NUCLEAR RADIATION: Similar to ground surface burst.

SHOCK: Water shock can cause damage to ships and underwater structures to a considerable distance.

AIR BLAST: Similar to ground surface burst.

EARLY FALLOUT: May be considerable.

SUMMARY: The general effects of a water surface burst are similar to those for a ground surface burst, except that the effect of the shock wave in water will extend farther than ground shock. In addition, water waves can cause damage on a nearby shore by the force of the waves and by inundation.

SHALLOW UNDERGROUND BURST

LIGHT, HEAT, AND INITIAL NUCLEAR RADIATION: Less than for a water surface burst, depending upon how much of the fireball breaks through the surface.

SHOCK: Ground shock will cause damage within about three crater radii, but little beyond.

AIR BLAST: Less than for a surface burst, depending on the depth of burst.

EARLY FALLOUT: May be considerable, if the depth of burst is not too large, and in addition there may be a highly radioactive base surge.

SUMMARY: Light, heat, initial nuclear radiation, and blast effects will be less than for a surface burst; early fallout can be significant, but at distances not too far from the explosion the radioactive base surge will be an important hazard. Water waves can also cause damage, as in the case of a water surface burst.

CONFINED SUBSURFACE BURST

LIGHT, HEAT, AND INITIAL NUCLEAR RADIATION: Negligible or none.

SHOCK: Severe, especially at fairly close distances from the burst point.

AIR BLAST: Negligible or none.

SUMMARY: If the burst does not penetrate the surface, either of the ground or water, the only hazard will be from ground or water shock. No other effects will be significant.

REFERENCES

The Effects of Nuclear Weapons.—Glasstone, Samuel, 1964.

EMP Threat and Protective Measures, DOD/OCD, TR-61, August 1970.

DCPA Attack Environment Manual.

NUCLEAR RADIATION MEASUREMENT

Since we cannot hear, see, smell, taste or feel nuclear radiation from the fallout, we must rely entirely upon instruments in order to DETECT its presence and MEASURE the degree of danger. In this chapter, then, we will look at:

HOW nuclear radiation may be *detected*

HOW nuclear radiation may be *measured*

WHAT instruments exist to do the detecting and the measuring

HOW do instruments operate

WHY do we need different types of instruments

WHAT are the units we use to measure nuclear radiation

INTRODUCTION

4.1 Man is aware of his environment through his senses. He can see, smell, taste, hear and feel. Yet, none of these senses will make him aware of the presence of nuclear radiation. This situation is not really unusual. In fact it is like his inability to respond directly to the waves of ultraviolet light and radar, television, or radio transmission. For example, a man may receive a serious sunburn due to overexposure to the sun's ultraviolet rays, yet his first indication of over-exposure may come several hours later when he feels pain. In this situation he was not aware of the ultraviolet rays during the exposure period; however, in a sense, he did detect the ultraviolet light indirectly since he certainly would be aware of a painful sunburn. Similarly, since man cannot rely on his senses to detect nuclear radiation he must rely on some *secondary* means such as instrumentation.

4.2 At the present time, nuclear radiation detection instruments are widely used in industry and research. X-ray films and Geiger counters are items of everyday conversation. In this chapter we will discuss the principles and theory of operation of many nuclear radiation detection instruments, or radiological instruments as we will refer to them. These instruments are very similar to other types of electronic equipment. *Their main distinguishing characteristic is their ability to respond to nuclear radiation.*

4.3 The term DETECTION is used in this text to include only the indication of the presence of nuclear radiation. The term MEASUREMENT will be reserved for both the detection and quantitative estimation of the amount of nuclear radiation present.

PRINCIPLES OF RADIATION DETECTION

4.4 Radiological instruments detect the interaction of radiation with some type of matter. The different principles of radiation detection are characterized by the nature of the interaction of the radiation with the detecting or sensing element. Several types operate by virtue of the ionization which is produced in them by the passage of charged particles. In other detectors, excitation and sometimes molecular disassociation play important roles.

4.5 During the 1890's, Henri Becquerel found that photographic plates, when placed in proximity to ores or compounds of uranium, were affected in the same manner as if they had been exposed to light. This occurred even when the plates were protected by sufficient covering to assure that the strongest light could not affect them. This date marked the discovery of radioactivity, and today this principle is still used to detect and measure the *product of radioactivity*, NUCLEAR RADIATION.

4.6 The photographic detection technique is relatively simple. As a charged particle passes through a photographic emulsion, it will generally cause changes which will result in a blackening of the emulsion when the film is developed. The photographic emulsion consists of finely divided crystals of a silver halide, usually silver bromide, suspended in gelatin and spread evenly on a glass, cellulose, or paper base. When charged particles strike the emulsion, some sort of ionization not well understood takes place. This local disturbance of the electrons in the crystals of silver bromide creates a latent image which is invisible to the eye when formed, but which can be developed later by chemical action. The chemical developer acts as a reducing agent to deposit metallic silver only at those points in the emulsion where radiation interacted and in proportion to the amount of radiation which acted on the silver salt. The amount of blackening on the film is a function of several factors: the time of exposure, the intensity of the exposure, the sensitivity of the film, and the chemical processes of development. By rigidly controlling these factors, the blackening of the film can be made proportional to the radiation exposure.

4.7 A second method of detecting radiation was again first employed by Becquerel and Rutherford in their early work with radioactive substances. Certain materials will produce small flashes of visible light when struck by alpha, beta, or gamma radiation. These flashes are called scintillations. The mechanism of formation of these scintillations is very complex but essentially it involves the initial formation of higher energy (or excited) electronic states of molecules (or atoms) in certain materials. Some of the absorbed energy which has been derived directly or indirectly from the incident radiation will be emitted in a very short time as photons of visible or ultraviolet light. These light photons are then converted into an electrical current by a photomultiplier tube and the current is measured. Since the light intensity and the resulting electrical current are proportional to the rate of radiation exposure, the instrument can be calibrated to read radiation exposure rates.

4.8 A third principle for detecting radiation is based on the fact that many substances undergo chemical changes when exposed to radiation. This is particularly true of chemicals in aqueous solutions where the decomposition of the water itself contributes to the reaction. If the extent of the chemical change can be conveniently measured, the reaction can be used for measuring radiation. There are several chemical reactions which may be utilized in this manner. One of the first used was the liberation of acid from a chlorinated hydrocarbon such as chloroform. Chloroform, water, and an indicator dye are sealed into a glass tube. As radiation penetrates the tube, hydrochloric acid is liberated from the chloroform. The liberation of this acid reduces the pH of the solution and causes a distinctive color change in the dissolved indicator. The extent of the color change is an estimate of the radiation exposure of the tube.

4.9 Becquerel's discovery that gases become electrical conductors as a result of exposure to radiation provides us with a fourth means of detecting and measuring radiation. When a high-speed particle or a photon passes through a gas, it may cause the removal of an electron from a neutral atom or molecule causing the formation of an ion pair. This process of ionization in a gas is the basic phenomenon in all **ENCLOSED GAS VOLUME INSTRUMENTS**. The electron produced may have rather high energies and may produce more ionization in the gas until its energy is expended and it is finally captured by an oppositely charged ion. If two oppositely charged collecting electrodes are introduced into the gas filled chamber, the ion pairs will migrate to their respective electrodes. Negative ions will move toward the positively charged electrode and the positive ions toward the negatively charged one. When the ions reach the electrodes, they will be neutralized, resulting in a reduction of the charge on the electrodes. In one type of instrument this loss in charge is used as a measure of the radiation exposure. In another type, batteries are used to replace the charge on the electrodes resulting in a current flow in the external circuit. Within certain limits, this ionization current will be proportional to the radiation exposure rate.

4.10 In addition to the four principles discussed above, there are several other principles which may be utilized for the detection of radiation, but to date these have not been as widely used.

TYPES OF RADIOLOGICAL INSTRUMENTS

4.11 In the development of radiological instruments, the choice of detector is an important factor. An equally important factor in their design is the type of information required by the user. Normally this information falls into two categories: the measurement of total accumulated exposure to radiation, and the instantaneous rate of exposure. The first is referred to as an **EXPOSURE MEASUREMENT** and the second, as an **EXPOSURE *RATE* MEASUREMENT**. As an example of a situation in which both types of information are required, consider the following. An area is contaminated with fallout. A person is required to enter the area and not exceed an exposure of 25 roentgens. This situation requires an instrument which will measure the total accumulated radiation exposure during the period of stay in the contaminated area. Instruments designed to provide such measurements are called **DOSIMETERS**. Next, assume that the operation to be performed will require two hours to complete. In order to determine if entry into the area is practical, it is necessary to know the instantaneous rate of exposure to which the person would be exposed in the contaminated area. Instruments designed to measure exposure rate are called **SURVEY METERS**.

4.12 It is important to emphasize that radiological instruments measure exposures and not absorbed or biological doses. Such **EXPOSURE** is a measure of the strength of the radiation field, while the **ABSORBED DOSE** is a measure of the amount of energy liberated in the absorbing material, and the **BIOLOGICAL DOSE** is a measure of the biological effect of a particular radiation absorbed by an individual. However, it is also important to emphasize that the ultimate objective for measuring an exposure to radiation is to relate that to a certain biological response of the exposed individual.

UNITS OF RADIATION MEASUREMENT

4.13 As discussed in Chapter 2, the roentgen is the unit of radiation exposure. This unit is based on the effect of X or gamma radiations on the air through which they pass. It is defined as that quantity of X or gamma radiation such that the associated corpuscular emission per cubic centimeter of dry atmospheric air at 0° centigrade and 760 mm of mercury produces, in air, ions carrying one electrostatic unit of charge of either sign (2.083×10^9 ion pairs/cc). Since this unit is rather large for measuring peacetime occupational exposures, the milliroentgen, which is equivalent to 1/1000th of a roentgen, is frequently used for measuring small exposures. Since dosimeters measure exposure, they measure in **ROENTGENS** or **MILLIROENTGENS**, while survey meters, which measure exposure rates, measure in **ROENTGENS** *per hour* or **MILLIROENTGENS** *per hour.* It is important to note that *the roentgen applies only to the measurement of X or gamma radiation, and does not apply to the measurement of alpha or beta radiation.*

4.14 These units of exposure and exposure rate are related by a time factor analogous to the relationship between total distance traveled and speed. For example, the total distance from Battle Creek, Michigan, to Detroit, Michigan, is approximately 120 miles. A person leaving Battle Creek and averaging 40 miles per hour would require three hours to travel to Detroit. Similarly, if a person entered a radioactive contaminated area where the exposure rate was 40 roentgens per hour and remained for three hours, his total accumulated exposure would be 120 roentgens. This, of course, assumes that the 40 roentgens per hour exposure rate remained constant. Just as it is difficult to maintain a speed of 40 miles per hour, so might it be difficult to maintain a radiation field of 40 roentgens per hour, since radioactive materials decay according to fixed natural laws. This decay will cause the 40 roentgens per hour exposure rate to decrease with time. However, if the radioactive material has a relatively long half-life, the decrease in exposure rate during a three-hour period may be negligible. (With fallout, especially in the early hours after detonation, the decrease in exposure rate will be appreciable during a three-hour period.)

DOSIMETERS

4.15 As indicated above, it is necessary in emergency operations to provide an instrument capable of measuring an individual's total exposure to radiation. It is clear from the definition of the roentgen that the measurement of ionization in air is basic to the determination of radiation exposure. In Civil Preparedness an ionization chamber employing the principle of enclosed gas volume has proved most satisfactory for exposure measurement.

4.16 To understand the operation of dosimeters, consider a foil leaf electroscope (Figure 4.16a) consisting of an outside metal shell in which is mounted an externally projecting electrode. An insulator such as amber or sulfur insulates the electrode from the outside case. Two narrow strips of a thin foil are cemented to the enclosed stem of the electrode to form the moving part of the electroscope. Normally, windows in the case serve for viewing the foil leaves. If an electrical charge is applied to the externally projecting electrode, it is transferred through the electrode to the foil leaves. Because of the mutual repulsion of like charges, the leaves will immediately repel each other until the electrical repulsion is just counter-balanced by the gravitational force tending to bring them back together. If the air in the enclosed chamber is ionized by radiation (Figure 4.16b), it becomes an electrical conductor and this permits the charge on the leaves to leak away. Since the electrical charge is reduced, the mutual repulsion of the leaves is reduced and they assume a position closer together. This same principle is basic to the operation of dosimeters. The electrostatic self-indicating dosimeter used in Civil Preparedness is nothing more than a sophisticated electroscope.

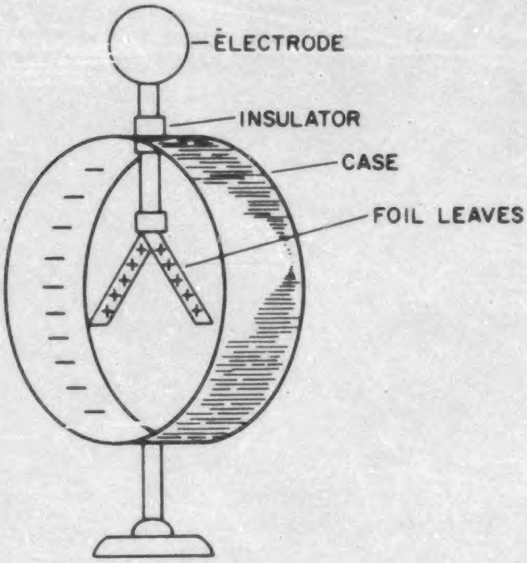

FIGURE 4.16a.—Charged electroscope.

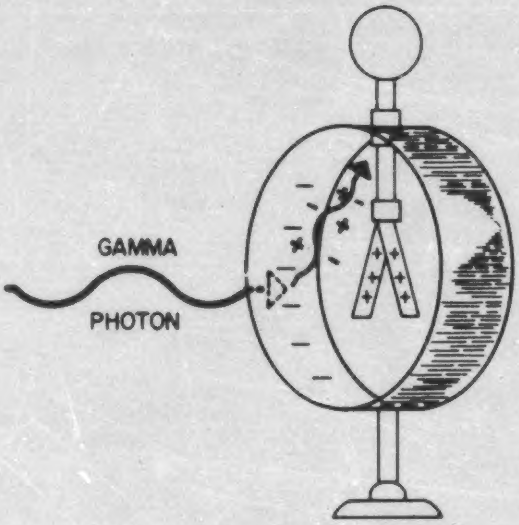

FIGURE 4.16b.—Radiation effect on charged electroscope.

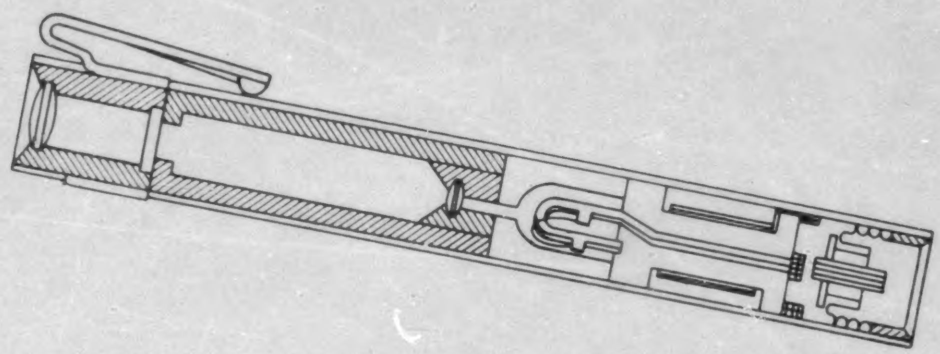

FIGURE 4.17.—Construction principles of an electrostatic self-indicating dosimeter.

4.17 The dosimeter consists of a quartz fiber electrometer suspension mounted inside an ionization chamber (Figure 4.17). The electrometer suspension is supported by means of a highly insulated material inside an electrically conducting cylinder. The enclosed air volume surrounding the electrometer suspension is the ionization chamber or the radiation sensitive component of the instrument. The indicating element is a five micron (1/5000 in.) quartz fiber which is part of the electrometer suspension. The quartz fiber has an electrically conducting coating evaporated on its surface and has the same form factor as the metal frame of the electrometer. In most dosimeters both frame and fiber are in the shape of a horseshoe, the fiber being attached to two offsets on the lower extremities of the frame.

4.18 The dosimeter contains an electrical capacitor in parallel with the electrometer suspension and the chamber wall. The range of the dosimeter is determined by the size of the capacitor, the chamber volume, the sensitivity of the electrometer, the pressure inside the ionization chamber and the optical system. Only pressure and capacitance variation offer a wide selection of ranges. Therefore, the function of the electrical capacitor is to change the range of the dosimeter. However, for a particular dosimeter, the range will be fixed by the selection of the capacitor at the time of its manufacture.

4.19 The charging switch assembly consists of a bellows and a contact rod, which is normally isolated from the electrometer suspension. Only when the dosimeter is placed on a dosimeter charger and the bellows depressed can contact be made between the rod and electrometer. This arrangement provides a very high electrical resistance, and the hermetic sealing allowed by such construction makes the dosimeter readings essentially independent of humidity and pressure changes.

4.20 Focused on the quartz fiber is a 75 to 125 power microscope which magnifies the image of the quartz fiber so that it is visible. The microscope consists of one objective lens, one eyepiece lens, and contains a scale or reticle at the real image of the quartz fiber. The scale is graduated in roentgens or milliroentgens depending on the range of the instrument.

4.21 In preparation for exposure to radiation, the dosimeter is charged to about 160 to 175 volts to bring the image of the quartz fiber to zero on the scale. (Figure 4.21). In charging the dosimeter, an external source of electrical power is used. The ionization chamber is held at ground potential and the metal frame and fiber of the electrometer assume the other extreme of the voltage difference. The fiber is repelled from the frame since both are at the same potential. The position of the quartz fiber will then vary with the potential difference. This variance is linear for the voltage range covered by the scale. When the instrument reads full scale, the potential difference is not zero but usually some intermediate voltage between 75 and 125 volts.

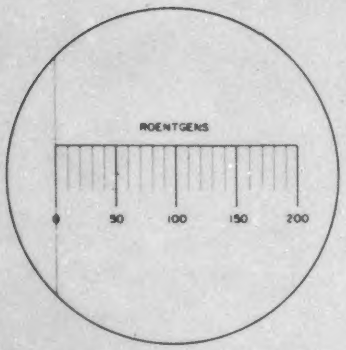

FIGURE 4.21.—Zero dosimeter reading.

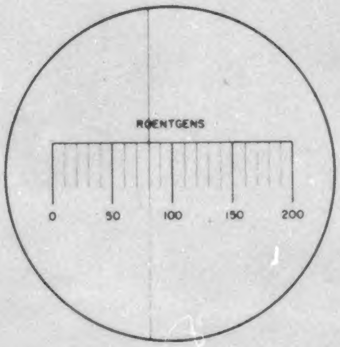

FIGURE 4.22b.—80 R dosimeter reading.

4.22 As the dosimeter is exposed to X or gamma radiation, the photons will interact with the wall of the ionization chamber producing secondary electrons (Figure 4.22a). These electrons enter the sensitive volume of the dosimeter and ionize the air molecules. Under the influence of the electrical field in the chamber, the ion pairs migrate to the electrode of opposite charge and are neutralized. This causes a proportionate discharge of the capacitor system and decreases the potential difference between the electrometer and the chamber wall. The quartz fiber now assumes a new position corresponding to the new potential difference. This is reflected by an up-scale movement of the hairline image of the quartz fiber (Figure 4.22b).

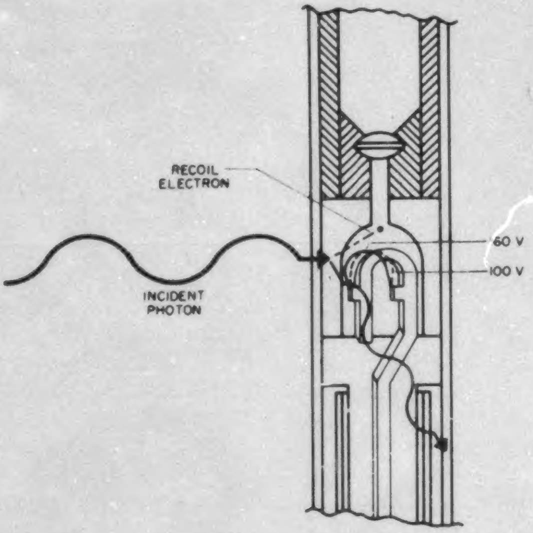

FIGURE 4.22a.—Operation of an electrostatic dosimeter.

The movement of the fiber is a function of the total amount of radiation to which the dosimeter is exposed, regardless of the rate of exposure to radiation.

4.23 If the dosimeter reading is zero at the start of a period, the exposure may be read directly from the dosimeter. However, any initial dosimeter reading must be subtracted from the final reading to obtain a correct indication of the total exposure. For example, if a dosimeter reads 10 rems at the start of a period and reads 55 rems at the end, the exposure during the period is 45 rems. Performance characteristics of dosimeters will be discussed in the next chapter.

DOSIMETER CHARGERS

4.24 The design of dosimeter chargers has progressed to the point that the later models all use transistorized circuits to provide the required charging voltage. Although some of the earliest chargers were not transistorized, probably all future ones will be because of the ease of opera-

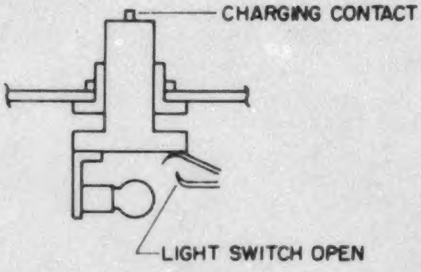

FIGURE 4.25a.—Initial condition.

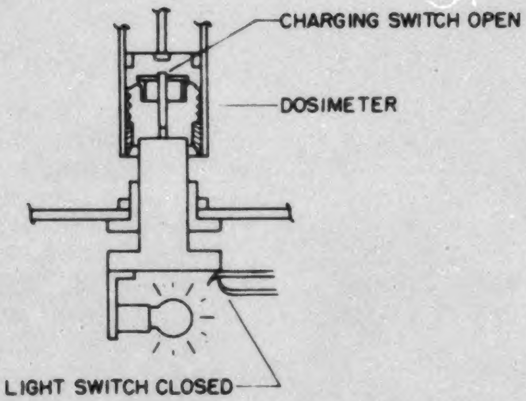
CHARGING SWITCH OPEN
DOSIMETER
LIGHT SWITCH CLOSED

FIGURE 4.25b.—Reading position.

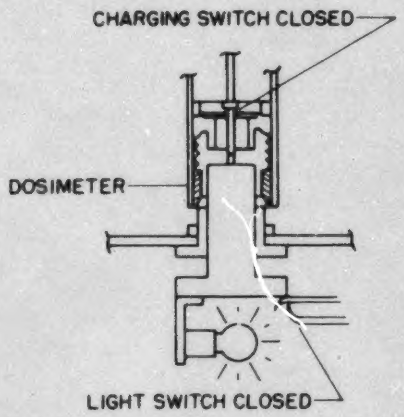
CHARGING SWITCH CLOSED
DOSIMETER
LIGHT SWITCH CLOSED

FIGURE 4.25c.—Charging position.

tion of the transistorized models and prolonged battery life.

4.25 In the transistorized chargers, the circuit is powered by a single 1.5 volt battery. The charging contact is shown in its initial condition in Figure 4.25a. When a dosimeter is placed on the charging contact and pressure is applied, the light switch closes and the bulb lights (Figure 4.25b). However, in this position the dosimeter cannot be charged, since the dosimeter charging switch is still open. Additional pressure must be applied to close this switch (Figure 4.25c). A transistor oscillator converts the direct current from a flashlight battery to alternating current so that the transformer can "step up" the battery voltage (1.5 volts) to the voltage required by the dosimeter. The current is then rectified by a diode and a potential of 220 volts maximum is available at the charging contact. A voltage control is used to adjust the output voltage to the exact value required to bring the dosimeter to zero.

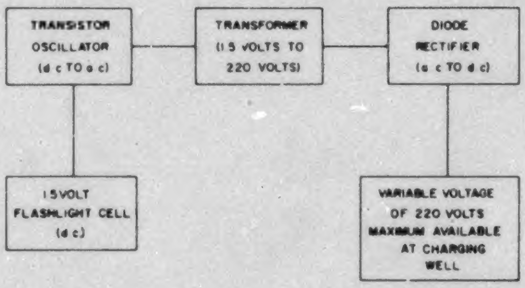
TRANSISTOR OSCILLATOR (d c TO a c)
TRANSFORMER (1.5 VOLTS TO 220 VOLTS)
DIODE RECTIFIER (a c TO d c)
1.5 VOLT FLASHLIGHT CELL (d c)
VARIABLE VOLTAGE OF 220 VOLTS MAXIMUM AVAILABLE AT CHARGING WELL

FIGURE 4.25d.—Simplified diagram of a CD V-750 dosimeter charger.

4.26 The mechanics of charging a dosimeter with this type of charger will be discussed in the next chapter.

SURVEY METERS

4.27 Our discussions in paragraph 4.11 established an additional requirement for an instrument which would measure exposure rate for use in survey operations. This instrument should measure the rate of formation of ion pairs rather than the total number that are produced by radiation. To date the enclosed gas volume principle has again proved most satisfactory for Civil Preparedness uses.

4.28 There are two types of Civil Preparedness exposure rate instruments which depend on the principle of electrical collection of ions (enclosed gas volume) for their operation. The characteristics of each depend mainly on the voltage at which the enclosed gas volume is operated. To understand their operation, it as necessary to investigate the behavior of ions in an electrical field. A system for investigating this behavior is illustrated in Figure 4.28. It consists of a chamber filled with air in which are fixed two parallel metal plates to act as electrodes. The electrodes are connected to a battery in such a way that the voltage can be increased steadily from zero to several hundred volts. A me-

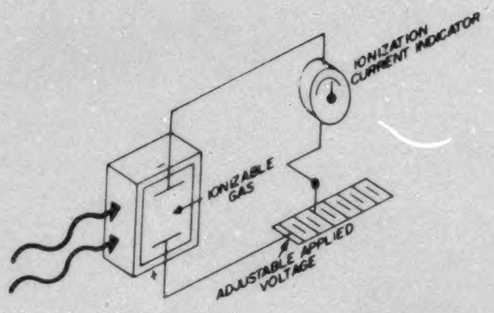

FIGURE 4.28.—Circuit for measuring the behavior of ions in an electrical field.

ter is placed in the circuit to measure the size of the electrical current produced.

4.29 Normally, the air in the ionization chamber will not conduct electricity and no current will flow in the external circuit. If a single ionizing radiation enters the chamber when a small difference of potential is applied to the electrodes, a number of ion pairs will be produced which will move to the oppositely charged electrode. When these charges collect, a current pulse will be measured by the meter in the external circuit. If a constant source of *gamma radiation* is used and the size of the current pulse is plotted against the voltage applied to the electrodes, the curve in Figure 4.29 will result. For convenience, the curve is divided into five regions, A, B, C, D and E.

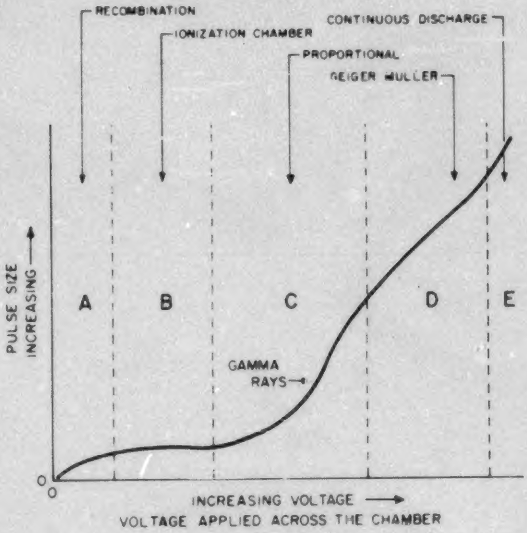

FIGURE 4.29—Pulse size vs. applied voltage for gamma radiation.

4.30 When the voltage applied to the electrodes is low, the electrical accelerating force is small. Thus, the ions move rather slowly and have sufficient time to recombine with other ions of opposite sign in the vicinity. The size of the pulse measured will be less than if all of the ion pairs formed succeeded in reaching the electrodes. As the applied voltage is increased, the ions travel faster. Their chances of recombination are lessened and the pulse size increases. Finally, as the applied voltage is increased sufficiently, all of the primary ion pairs will be collected at the electrodes. This voltage is referred to as the saturation voltage. As the electrode voltage increases above this point, no increase in the size of current pulse is immediately experienced since all of the primary ion pairs have been collected. Therefore, the pulse size remains relatively constant throughout region B of the curve in Figure 4.29. The actual voltage range over which the pulse size is constant depends on many factors, which include the gas used in the chamber, the pressure of the gas, and the distance between the electrodes.

4.31 Region B of the curve is referred to as the ionization chamber region, and instruments designed to operate in this region are called ionization chamber instruments. Since batteries are usually used as the source of electrical power in RADEF instruments, this region is well adapted for their use. If the operating voltage for a particular ionization chamber is chosen at the upper end of the plateau, the size of the electrical pulse produced by radiation will not vary appreciably as the electrode voltage decreases with both age and use of the batteries.

4.32 As the applied voltage is increased beyond the ionization chamber region, the size of the pulse is increased. In region C of the curve, the increased electrical field causes the primary ions to gain sufficient kinetic energy to cause secondary ionization of other atoms and molecules in the gas. This secondary ionization leads to an increase in the size of the pulse, which amounts to an internal amplification of the pulse in the enclosed gas volume. This amplification increases with applied voltage and remains linear until an internal amplification factor of approximately 1,000 is obtained. Region C is the proportional region, and instruments operating in this region are called proportional counters. No Civil Preparedness instruments operate in this range.

4.33 In the proportional region, a large number of secondary ion pairs are produced at only one point within the enclosed gas volume. However, when the applied voltage is increased further, the secondary ionization occurs throughout the enclosed gas volume. Therefore, since the amplification is so great in the Geiger Muller region, the size of the pulse is almost independent of the number of ion pairs produced. Thus, one initial ionizing event occurring within the enclosed gas volume will initiate an ELECTRON AVALANCHE (explained in paragraph 4.46) which will spread quickly throughout the entire tube. Instruments operating in this region will produce one large pulse for each ionizing event to which the tube is subjected. Gas amplification factors of the order of 100 million are common.

4.34 When the operating voltage exceeds the Geiger Muller region, it is so high that once ionization takes place in the gas, there is a continuous discharge of electricity so that it cannot be used for counting purposes. The upper end of the Geiger Muller region is marked by this breakdown voltage.

OPERATION OF ION CHAMBER SURVEY METERS

4.35 The development of ionization chamber survey meters has also progressed to the point that the later models of ionization chamber survey meters and probably future models will use a modification of the simplified schematic circuit drawn in Figure 4.35. The basic components of this circuit are: (1) an ionization chamber, (2) a source of electrical power, and (3) a measuring circuit consisting of an electrometer tube and an indicating meter.

4.36 The detecting element of the instrument is an hermetically sealed air-equivalent ionization chamber. It consists of a conducting cylindrical container of plastic and steel called the shell and a thin conducting disk, which is located in the center of the shell, called the collector. These are respectively the positive and negative electrodes and are insulated from each other by an extremely high resistance feed-thru insulator. A collecting voltage is applied to these two chamber electrodes.

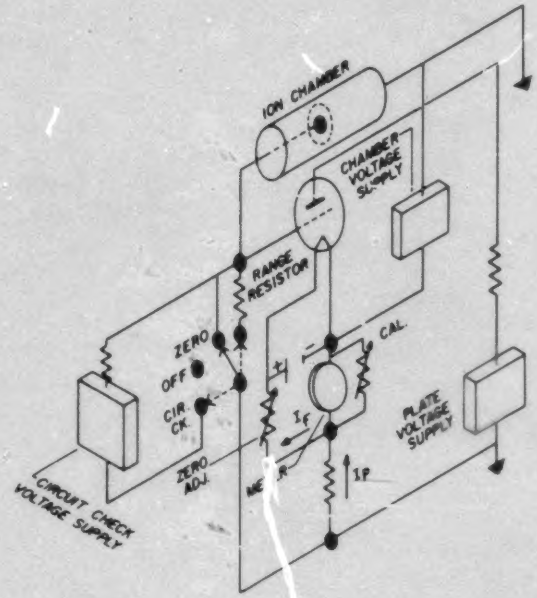

FIGURE 4.35.—Simplified circuit diagram for a Civil Preparedness ion chamber survey meter.

4.37 When the instrument is exposed to radiation, some of the energy of the radiation field is absorbed within the walls of the ionization chamber. As a result, electrons are ejected from the walls into the air contained within the chamber. As these electrons traverse the chamber, they create a considerable amount of ionization in the air. Under the influence of the electric field existing between the chamber electrodes, the ions move to the electrode having the opposite charge; that is, positive ions move toward the collecting disk and the negative ions toward the shell. The arrival of these ions at the electrodes constitutes a current, the magnitude of which is proportional to the number of ions collected. Since the number of ions created is proportional to the radiation exposure rate, this ionization current is proportional to the exposure rate in the ionization chamber.

4.38 A very small ionization current (approximately 0.00005 microamperes at full scale on the most sensitive range) flows through a "high-meg" resistor and develops a measurable voltage. This voltage is applied to the grid of a vacuum tube called an electrometer tube because it is capable of measuring voltages at extremely small current values. The electrometer tube is connected as a triode. Its three elements are: (1) the filament which, when heated by current from the 1.5 volt battery, emits electrons, (2) the grid, which controls the flow of these electrons according to the voltage applied to it, and (3) the plate, which receives the electrons and passes them to the circuit in the form of a measurable current.

4.39 Measurement of the grid voltage of the electrometer tube is accomplished by metering the change in plate current (Ip) directly. With the selector switch in the zero position, the high-meg range resistor is removed from the grid circuit so that no signal voltage can be developed as a result of any ionization chamber current. The quiescent value of the plate current is then exactly balanced by the bucking current (I_b) so that the resultant current through the meter is zero. The bucking current is adjusted by means of the zero adjust potentiometer.

4.40 When the selector switch is placed in a range position, one of the high-meg range resistors is reinstated into the grid circuit. The ionization current, therefore, produces a positive signal voltage across this resistor, which in turn results in an increase in the plate current. Thus, the resultant current through the meter is no longer zero and the meter measures the increase in plate current. Since this change is proportional to the magnitude of the radiation field, the meter scale can be calibrated directly in roentgens per hour.

4.41 Prior to use for measuring exposure rates, the static plate current must be cancelled by the reverse filament current to obtain zero meter current (zero reading) at zero radiation levels. Since it will probably be necessary to zero the instrument in a radiation field, a section of the selector switch is used to short out the high-meg resistor and prevent any ionization signal from being sensed by the grid circuit. Thus, when the selector switch (Figure 4.41) is in the zero position, zero radiation conditions are duplicated and the zeroing process can be accomplished even in the presence of a high radiation field.

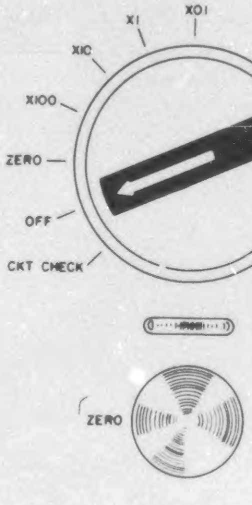

FIGURE 4.41.—Selector switch and zero control.

4.42 The proper functioning of the measuring circuit including the batteries may be checked by turning the selector switch to the circuit check position (Figure 4.41) and observing the meter readings. In this position, a predetermined voltage is impressed on the grid of the electrometer tube to make the meter read approximately full scale. Deterioration of any of the components or batteries in the circuit will change this reading. Therefore, this voltage can be used to check the entire circuit with the exception of the ionizaton chamber and high-meg resistor.

4.43 All radiological instruments should be calibrated prior to their initial field use and periodically thereafter. This may be done by using a calibrated source of radioactive material. If the instrument does not read properly when placed in a radiation field of known exposure rate, the calibration control can be adjusted to give the desired meter indication corresponding to the known exposure rate.

4.44 Sensitivity of the instrument is changed by switching high-meg resistors. This is accomplished by the selector switch (Figure 4.41). On each range the meter reading must be multiplied by 0.1, 1, 10, and 100 to obtain the measured exposure rate.

OPERATION OF GEIGER COUNTERS

4.45 Geiger counter operation is based on the ionization of gases similar to the operation of ionization chamber survey meters. In the ionization chamber instrument, a very small current is developed, amplified, and then measured on a sensitive meter. The current is smooth in character since the many ionizing events are averaged. Geiger counters differ materially in that the current flow is not smooth but it is delivered in surges or pulses.

4.46 Geiger counters take advantage of the extreme gas amplification that can be obtained when high accelerating voltages are applied to the electrodes within the chamber. As ion pairs are formed in the gas, they will move with increasing velocity toward the electrodes until either recombination or collision with another air molecule occurs. The average distance between successive collisions is referred to as the mean free path. If the mean free path is small and the accelerating voltage relatively high, each ion will gain only a small amount of energy between collisions. As the operating pressure of the Geiger tube is reduced, the mean free path is increased, causing the ions to gain additional energy between collisions. When the kinetic energy of the ions is sufficient, they will cause secondary ionization. These secondary ions will also be accelerated by the electrical field and will produce further ionization. This cumulative increase in ions is similar to a single rock precipitating an avalanche and is, therefore, often referred to as **ELECTRON AVALANCHE**. This avalanche may produce as many as 100 million other ion pairs for each initial ion pair produced in the chamber. The gas amplification factor of the tube under these conditions would be about 100 million.

4.47 Consider a Geiger tube filled with a gas, frequently argon or neon, to an absolute pressure of ten centimeters of mercury and exposed to a constant radiation intensity. If the number of pulses per second occurring within the tube is plotted against the voltage applied to the electrodes, a characteristic curve similar to Figure 4.47 is produced. This curve differs from the curve in Figure 4.29 in that the number of pulses is plotted against the applied voltage rather than the size of the pulse. Since, under the operating conditions placed on the tube, no gas amplification occurs at low voltages, there is a threshold below which no pulses will be recorded. As the voltage increases and the gas amplification factor increases, the number of pulses increases. At first, only the most ionizing particles would be counted and the weak ones lost. As the voltage increases, however, practically every particle entering the tube will be counted. When this condition occurs, the

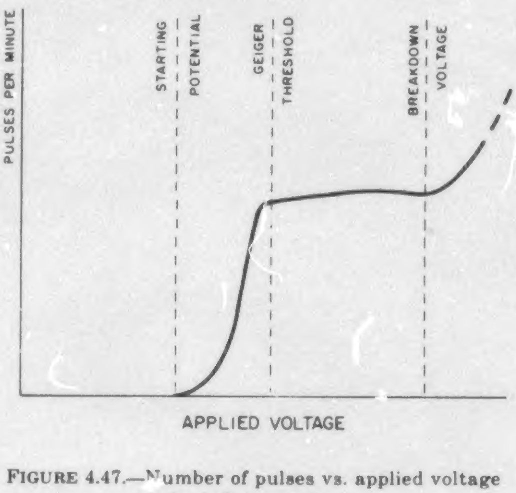

FIGURE 4.47.—Number of pulses vs. applied voltage for a Geiger tube.

curve will flatten out. This is called the Geiger plateau and it is desirable that it be long and flat so that the counting rate does not depend strongly upon the applied voltage. Above the Geiger plateau voltage, the tube goes into a continuous discharge state and is not suited for counting purposes.

4.48 Avalanche formation will take place in the vicinity of the central wire of the Geiger tube, since here the electric field is high and each electron on its way to the central wire acquires sufficient energy for further ionization in each mean free path. Thus, a large number of electrons and positive ions will be formed near the center wire in the first avalanche. The electrons having a small mass and already positioned close to the central wire will move toward it with high velocities and will be completely collected in about one millionth of a second. The heavier positive ions travel more slowly out to the negatively charged cylinder. This causes a positive ion cloud or space charge which reduces the electric field and stops the avalanche formation. In about one ten thousandth of a second, the positive ions or space charge will reach the cylinder wall. As a positive ion approaches very close to the cylinder, it will pull an electron from the cylinder and be converted to a neutral molecule. Generally, the electron will move into one of the upper energy levels of the molecule resulting in an excited molecular state. The electron will move to the ground state and in so doing may produce photons in the ultraviolet region which will have sufficient energy to liberate photoelectrons from the metal cylinder. With high tube voltages, this single photoelectron will start a second avalanche and thus the entire process will be repeated over and over again. This repeated discharge must be stopped and the tube restored to its initial condition if the tube is to be used to measure radiation. The process by which the tube is prevented from repeating the discharge is called quenching.

4.49 Quenching may be accomplished either electronically or by adding a suitable gas to the Geiger tube. Utilizing a suitable electronic circuit, the operating voltage of the Geiger tube can be momentarily reduced below the voltage required for a self-perpetuating discharge as soon as the avalanche begins. Other Geiger tubes, called self-quenched tubes, utilize a small amount of alcohol or halogen gas to quench the discharge. In this case, both argon and alcohol molecules participate in the avalanche. As the positive ions migrate to the electrode, the argon ions having an ionization potential of 15.7 volts collide with alcohol molecules with an ionization potential of 11.3 volts. This difference in ionization potential causes the charge to be transferred to the alcohol molecules and only these ions reach the electrode. As they approach the electrode, they will pull electrons from the cylinder wall. The energy of the excited states of the alcohol molecules will disassociate other alcohol molecules rather than cause further ionization. The self-perpetuating discharge is prevented in this manner.

4.50 Since some of the quenching gas is disassociated at each discharge, the supply is constantly depleted and the Geiger tube will have a limited useful life of about one billion counts. Halogens, particularly chlorine and bromine, are currently being used as quenching gases in argon-filled counters and have some advantages over the alcohol-quenched tubes. Since the halogen atoms will recombine after the disassociation process, tubes filled with this gas will have essentially an unlimited life. Halogens, however, are extremely reactive gases and great care must be exercised in choosing electrode materials.

4.51 Figure 4.51 illustrates a typical simplified circuit diagram of a Geiger counter. The Geiger tube consists of a thin cylindrical shell which serves as the cathode, a fine wire anode suspended along the longitudinal axis of the shell, and a small amount of a quenching gas. A potential of approximately 900 volts is applied between the two electrodes.

4.52 When radiation penetrates the tube, a gas molecule is ionized. The resulting ion pair is accelerated toward the electrodes by the electric field. Because of the high accelerating voltages, the creation of additional ions is very rapid, thus producing a discharge (avalanche) in the tube. This discharge results in a pulse in the external circuit. The frequency of such pulses is proportional to the strength of the radiation field. The small amount of halogen gas in the tube serves to stop each discharge and restore the tube to its initial condition.

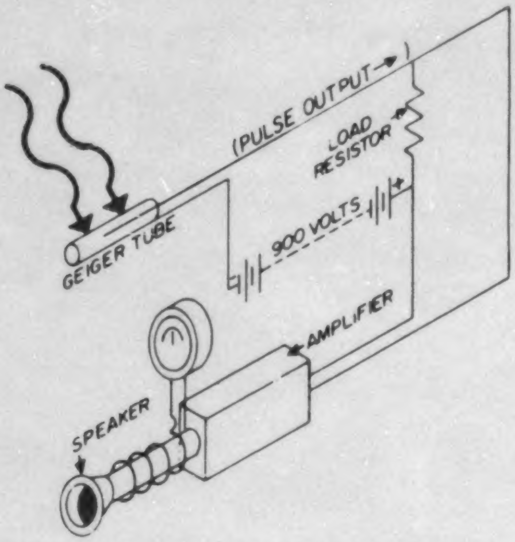

FIGURE 4.51.—Simplified circuit of a Geiger counter.

4.53 The pulse output from the Geiger tube is amplified by conventional electronic means and then measured by a sensitive meter which sums up the radiation effects in the form of a reading in either counts per minute or, in the case of gamma rays, milliroentgens per hour. In addition to the meter indication, most Geiger counters are provided with headphones which detect the pulses from the Geiger tube and produce an audible click.

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Nuclear Radiation Physics.—Lapp, Ralph E. and Andrews, Howard L., Prentice-Hall, Inc., 1972.

RADIOLOGICAL EQUIPMENT

Having covered the theory of radiological instrumentation in the previous chapter, we are ready to move to the practical aspects of detecting and measuring nuclear radiation. This means it is time for a look at the various types of radiological equipment available and the different situations in which each item would be applied. In addition to learning what we have in the way of different pieces of equipment, we will also be shown:

WHAT the equipment can do

WHAT it cannot do

WHEN to use a particular piece of equipment

HOW to check it, operate it and care for it

RADIOLOGICAL INSTRUMENT REQUIREMENTS

5.1 There is no exact equivalent of combat experience upon which to base the requirements for Civil Preparedness radiological equipment. However, extensive tests of nuclear weapons under known conditions have indicated the kinds and extent of residual radiation that could result from the use of such weapons. The knowledge gained from these and other types of experiments makes it possible to relate radiation conditions to biological effects on man and thus establish equipment requirements.

5.2 Because of the many variables associated with the detonation of a nuclear weapon, it is not possible to predict accurately the radiation levels that will result from fallout. Furthermore, no single instrument meets all of the operational requirements that might result from a nuclear attack. Therefore, a wide capability for radiation measurement is required. DCPA has developed several instruments that, together, provide this wide monitoring capability. These instruments fall into two distinct classes:

Radiation survey meters for use by monitoring personnel in determining contaminated areas and radiation exposure rates.

Exposure measuring instruments (dosimeters) needed by all Civil Preparedness workers such as fire fighters, first aiders, rescue teams, and radiation monitors who have to perform their emergency duties in contaminated areas.

5.3 **SURVEY METERS** provide the information required for locating contaminated areas and for estimating the degree of the hazard. Since it would not be practical to compute your total radiation exposure from survey meter measurements if the exposure rate varied during the exposure period, **DOSIMETERS** are also needed for recording the total amount of an individual's exposure. Estimates of total exposure and related biological effects can be made on the basis of exposure rate measurements, decay rates, and probable exposure times, but these estimates should be used for planning purposes only. Determination of *actual* exposure times and exposures during emergency operations must be based on both the exposure rate, as read on survey meters, and on the total exposure as indicated by dosimeters.

5.4 Alpha, beta, and gamma radiations may be present in radioactive fallout. Since the hazards from these radiations will be discussed in detail in later chapters, it suffices here to indicate that gamma radiation is an external hazard and, under certain conditions, beta radiation may also be an external hazard. In addition, these three types of radiation may be internal hazards.

5.5 Alpha radiation does *not* present an external hazard, since it will not penetrate beyond the surface layers of the skin. Alpha emitters must get inside the body before they can cause appreciable damage. Because alpha emitters will probably not present a significant hazard relative to the beta and gamma hazard immediately following a nuclear attack and for some time thereafter, and further, because of the difficulty in developing *portable* alpha measuring instruments, DCPA does not provide a standard instrument sensitive to this type of nuclear radiation. During the recovery phase, the determination of the seriousness of the alpha contamination in food and water will probably be accomplished by laboratory-type instruments.

MEASURING BETA AND GAMMA RADIATION

5.6 Since the biological effects of beta and gamma radiation differ, radiological instruments must discriminate between them. Measurement of beta radiation is complicated by the very wide range of energies of these particles. Most beta detection instruments will not respond to extremely low energy beta particles. However, that portion of the beta radiation that *can* be detected *should* be detected, so that its proportion to the total radiation exposure can be determined. This is necessary to estimate possible damage by each type of radiation. It should be noted, however, that the units of measurement used on radiological instruments to show accumulative exposures and exposure rates of gamma radiation are the roentgen and the roentgen per hour and the roentgen is defined in terms of *X or gamma radiation* exposure in air. Therefore, these units do not relate directly to measurements of beta radiation. Consequently, meter indications of beta radiation can be interpreted only in a general way.

5.7 The sensitivity requirement of a radiation instrument depends upon the type of information it is expected to provide. An instrument used to measure the contamination of personnel, food, water, equipment, or living quarters must indicate very small amounts of radiation above normal background radiation. This type of instrument would therefore have little use in areas of heavy contamination.

5.8 To provide adequate monitoring, portable radiological instruments should be capable of measuring gamma exposure rates as high as 500 R/hr and also indicate when exposure rates exceed this figure. Measurement above this amount is not necessary for portable survey instruments, because a higher level of radiation would be so dangerous as to preclude further surface operations.

5.9 When surface level exposure rates are very high or when rapid monitoring of large areas is required, aerial monitoring may be practical. Survey meters designed for this purpose must be extremely sensitive in order to give correct readings of radiation levels on the ground. Remote reading instruments used to indicate radiation levels outside fallout shelters are also required and should indicate gamma exposure rates up to at least 500 R/hr.

5.10 Within the entire group of radiological instruments developed by DCPA, the capability exists for measurement of ionizing radiation exposure rates ranging from a minimum of natural background radiation to a maximum of 500 R/hr. This wide range of measurement capability is considered adequate for all operational needs.

TYPES OF DCPA RADIOLOGICAL INSTRUMENTS

5.11 Each of the DCPA radiological instruments will be dvscussed in terms of its uses, significant operating characteristics, important specifications, and the care and maintenance to be accomplished by the instrument operator or monitor.

CD V–700

5.12 The CD V–700 radiation survey meter (Figure 5.12) is a highly sensitive low-range instrument that can measure gamma radiation and discriminate between beta and gamma radiations. DCPA recommends its use primarily in long-term clean-up and decontamination operations.

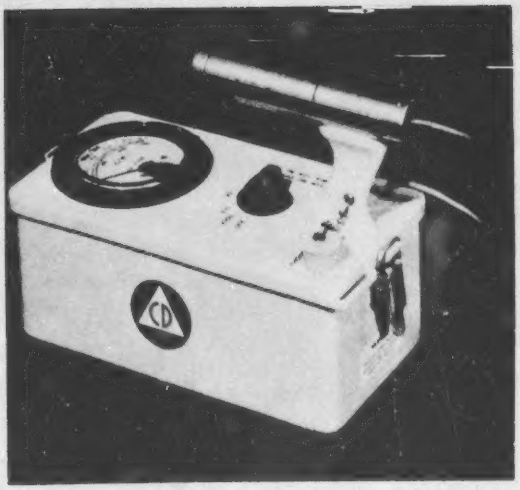

FIGURE 5.12.—CD V-700, low range beta-gamma survey meter.

5.13 The instrument can also be used in training programs where low radiation exposure rates will be encountered. The detecting element of the CD V-700 is a Geiger tube shielded so that only the gamma exposure rate is measured or beta and gamma can be detected together with the shield open. A headphone for audible indication is supplied with this instrument.

IMPORTANT SPECIFICATIONS OF THE CD V-700

1. RANGE: 0-0.5, 0-5.0, 0-50 milliroentgens per hour.
2. DETECTS: beta and gamma radiation.
3. ACCURACY: ± 15% of true exposure rate from cobalt 60 or cesium 137.
4. RESPONSE TIME: 95% of final reading in approximately 8 seconds.
5. TEMPERATURE: instrument shall operate properly from − 10° F to + 125° F.
6. PRESSURE: instrument shall operate properly from sea level to 25,000 feet.
7. JAMMING: exposure rates from 50 milliroentgens per hour to 1 roentgen per hour shall produce off-scale readings.
8. LIGHT SENSITIVITY: direct sunlight shall not affect the operation of the instrument.
9. ELECTROMAGNETIC INTERFERENCE: the instrument shall operate properly in normally encountered electromagnetic fields.
10. OPERATIONAL CHECK SOURCE: a permanently sealed radioactive source shall provide a reading of 2 mR/hr ± 0.5 mR/hr when the probe, with beta shield *open*, is held over it.
11. BATTERY LIFE: 100 hours continuous use (minimum).

OPERATOR USE, CARE AND MAINTENANCE OF THE CD V-700

5.14 *Batteries.*—Whenever the instrument fails to respond to the radioactive source on the side of the instrument, check the batteries. Replace bad batteries in accordance with the instructions in the manual accompanying the instrument.

During extended storage periods the batteries should be removed from the instrument and stored in a cool, dry place.

Battery contacts should be inspected monthly, and any dirt or corrosion present should be removed. Whenever the instrument is not in use, MAKE CERTAIN IT IS TURNED OFF; otherwise, the batteries will be depleted and the instrument rendered ineffective.

5.15 *Geiger Tube.*—The Geiger tubes in the later models of the CD V-700 are halogen quenched so that their operating life is unaffected by use and, therefore, rarely require replacement. However, when fresh batteries are installed and the instrument does not work correctly, it may be necessary to replace the Geiger tube. To check for a faulty Geiger tube, replace the suspected tube with a good tube from a properly operating CD V-700.

5.16 *Headphones.*—If the operator chooses to use the headphones with the instrument, they may be screwed into the connector provided at the lower left corner of the instrument cover. In using the headphone, the operator will note that each pulse or count is indicated by a distinctly audible click. When the headphones are not in use, the protective cap on the headphone receptacle should be replaced.

5.17 *Carrying Strap.*—The instrument may be carried in the hand or by a strap over the shoulder. The strap anchors are arranged in such a way that the meter is visible when carried over the right shoulder.

5.18 *Controls.*—There is only one control on this instrument for the operator's use. This control, called the selector switch, includes an off position and three ranges, labeled X 100, X 10, and X 1. On the X 1, the X 10 and X 100 ranges, the meter readings must be multiplied by a factor of 1, 10, and 100, respectively, to obtain the measured exposure rate.

5.19 *Operational Check.*—The selector switch should be turned to the X 10 range. The beta shield on the probe should be rotated to the fully open position and the probe placed as close as possible to the radioactive sample located either on the bottom surface of the case or underneath the manufacturer's name plate (see instrument manual). The open area of the probe must be directly facing the radioactive sample. The meter should be adjusted to read 2 ± .5 milliroentgens per hour. No external radiation must be present when making this check. The source should be used to determine the operability of the instrument only. It is not intended to replace the need for calibrating the instrument against a known source.

5.20 *Calibration.*—The instrument should be calibrated periodically to verify that it is measuring correctly.

5.21 *Contamination.*—At all times the operator should attempt to prevent radiological contamination of the instrument, particularly of the probe. In case of contamination, the instrument can be cleaned by a cloth dampened in a mild soap solution.

CD V–715

5.22 The CD V–715 (Figure 5.22) is a high-range gamma survey meter for general postattack operational use. The detecting element of the CD V–715 is an ionization chamber. The instrument is designed for ground survey and for use in fallout shelters. It will be used by a radiological monitor for the major portion of survey requirements in the period immediately following a nuclear weapon attack. The CD V–715 has replaced the now obsolete CD V–710 medium-range 0–50 R/hr gamma survey meter.

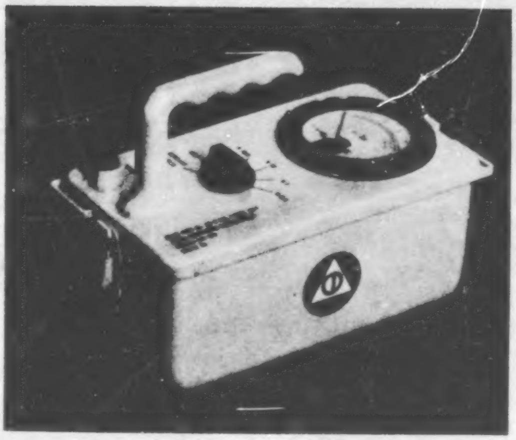

FIGURE 5.22.—CD V–715, high-range gamma survey matter.

IMPORTANT SPECIFICATIONS OF THE CD V–715

1. RANGE: 0–0.5, 0–5.0, 0–50, 0–500 roent-operate from −20° F. to 110° F.
2. DETECTS: gamma radiation only.
3. ACCURACY: ± 20% of true exposure rate from cobalt 60 or cesium 137.
4. SPECTRAL DEPENDENCY: ± 15% for gamma radiation energies between 80 keV and 1.2 MeV.
5. RESPONSE TIMES: 95% of final reading in 9 seconds.
6. TEMPERATURE: instrument shall operate properly from − 20° F to + 125° F.
7. PRESSURE: instrument shall operate properly from sea level to 25,000 feet.
8. JAMMING: exposure rates from 500 roentgens per hour to 5,000 roentgens per hour shall produce off-scale readings at the high end.
9. ELECTROMAGNETIC INTERFERENCE: instrument shall operate properly in normally encountered electromagnetic fields.

OPERATOR USE, CARE AND MAINTENANCE OF THE CD V-715

5.23 *Batteries.*—Battery replacement is normally required whenever the instrument can no longer be zeroed or when the meter indicates below the "CIRCUIT CHECK BAND". Batteries should be replaced in accordance with the instruction in the instrument manual. *If the instrument is to be stored for more than a few weeks, the batteries should be removed and stored in a cool dry location.* For instruments in continuous use, batteries should be removed monthly and the battery contacts cleaned of any dirt or corrosion present.

5.24 *Controls.*—Two controls are provided. One control, the selector switch, has seven positions: circuit check, off, zero, X 100, X 10, X 1, and X 0.1 ranges. On the X 0.1, X 1, X 10, and X 100 ranges, the meter readings must be multiplied by a factor of 0.1, 1, 10, and 100 respectively in order to obtain the measured exposure rate. The second control, the zero control, is used to adjust the meter reading to zero during an operational check.

5.25 *Carrying Strap.*—The instrument is equipped with a carrying strap which may be adjusted to any length to suit the operat

5.26 *Operational Check.*—Turn the selector switch to the zero position, wait a minute or two for the electrometer tube to warm up and adjust the zero control to make the meter read zero. Turn the selector switch to the circuit check position. The meter should read within the red band marked "Circuit Check". As the selector switch is turned through the zero position to the four ranges, recheck the zero setting. Turn the selector switch to the X 100, X 10, X 1, and X 0.1 range. When no radiation is present, the reading should not be more than two scale divisions up scale. If difficulty is encountered with any step in the operational check, refer to the instrument manual for corrective procedure. Many models have internal adjustments which may correct the difficulty. During normal use, the CD V-715 should be zeroed frequently, at least every half hour.

5.27 *Calibration.*—The CD V-715 should be calibrated periodically to verify the accuracy of its measurements.

5.28 *Contamination.*—The operator should attempt to prevent radiological contamination of the instrument at all times. In case of contamination, the instrument can be cleaned by a cloth dampened in a mild soap solution.

5.29 *Modification (CD V-717).*—Some of the CD V-715's are equipped by the manufacturer with a removable ionization chamber attached to 25 feet of cable. This modification, called the CD V-717, provides a remote reading capability for fallout monitoring stations. The operating characteristics are identical to the CD V-715 except that the removable ionization chamber must be placed outside the shelter in an unshielded area and protected from possible contamination by placing it in a bag or cover of light-weight material. All readings may then be observed from within the fallout monitoring station. After the early periods of heavy fallout and the requirement for a remote reading instrument diminishes, the removable ionization chamber should be checked for contamination with the CD V-700, decontaminated if necessary, and returned to the case. The CD V-717 may then be used for other monitoring operations.

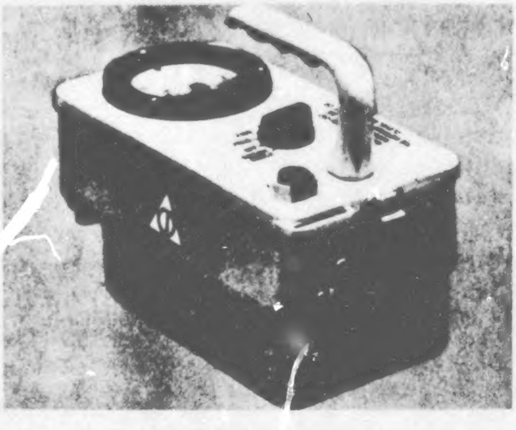

FIGURE 5.29.—CD V-717, Remote Ion Chamber.

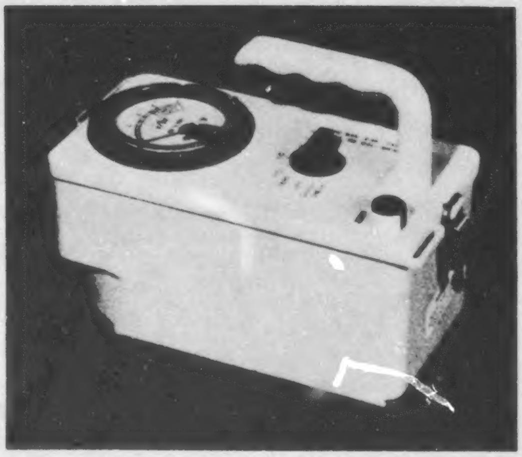

FIGURE 5.30.—CD V-720, beta-gamma survey meter.

CD V–720

5.30 The CD V-720 (Figure 5.30) is a high range (0–500 R/hr) beta-gamma survey meter designed for postattack use by monitors. It will be used in high-level contamination areas where civil preparedness operations are necessary and for making high-level beta radiation determinations. Many of the Federal agencies maintain a sizeable number of these instruments to fulfill their special requirements. The detecting element of the CD V-720 is an ionization chamber, shielded so that gamma radiation only can be measured, or both beta and gamma can be detected with the shield open.

OPERATOR USE, CARE AND MAINTENANCE OF THE CD V–720

5.31 The use, care, and maintenance of the CD V-720 are similar to the use, care, and maintenance of the CD V-715. (Refer to paragraphs 5.23 to 5.28 for details.)

CD DOSIMETERS

5.32 Personnel who must work in contaminated areas require radiation integrating instruments to keep them continuously informed of their exposure. For this purpose DCPA recommends the use of the self-indicating quartz-fiber electrostatic dosimeter (Figure 5.32).

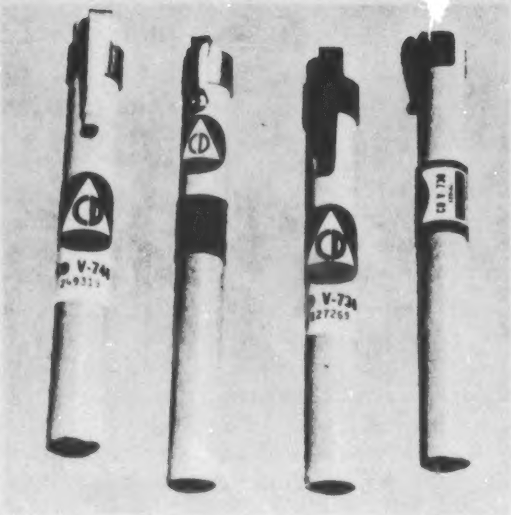

FIGURE 5.32.—CD operational dosimeters.

5.33 DCPA has procured three dosimeters for operational use. These are the CD V-730, with a range of 0–20 roentgens, the CD V-740, with a range of 0–100 roentgens, and the CD V-742, with a range of 0–200 roentgens. The CD V-730 is used when a monitor expects small repeated exposures over a long period of time. The CD V-740 and CD V-742 dosimeters are recommended for use when personnel could be accidentally exposed to large doses of radiation. They should be used when personnel are required to enter fields of high radiation or remain in low radiation fields for long periods during postattack survival and recovery missions. After current stocks of the CD V-730 and CD V-740 are depleted, DCPA will procure and issue the CD V-742 only. For training purposes, the CD V-138 with a range of 0–200 milliroentgens is recommended.

IMPORTANT SPECIFICATIONS OF THE CD DOSIMETERS

1. RANGE: CD V-138 0–200 milliroentgens
   CD V-730 0–20 roentgens
   CD V-740 0–100 roentgens
   CD V-742 0–200 roentgens
2. DETECT: gamma radiation.

3. ACCURACY: ± 10% of true exposures from cobalt 60 or cesium 137
4. SPECTRAL DEPENDENCY: ± 20% of true exposure for gamma radiation energies between 50 keV and 2 MeV.
5. ELECTRICAL LEAKAGE: CD V–730 and CD V–742. Beginning ten minutes after exposure, leakage shall not exceed 5% of full scale in a four-hour period. Beginning 48 hours after exposure, leakage shall not exceed 2% of full scale in 96 hours.

   CD V–740. Leakage shall not exceed 2% of full scale in 24 hours.

   CD V–138. Beginning 10 minutes after exposure, leakage shall not exceed 5% of full scale in 4 hours. Beginning 48 hours after exposure, leakage shall not exceed 3% of full scale in 48 hours.
6. GEOTROPISM: reading shall not vary more than ±4% of full scale when rotated about the horizontal axis.
7. TEMPERATURE: instrument shall operate properly from −40° F to +150° F.
8. PRESSURE: instrument shall operate properly from sea level to 25,000 feet.
9. SHOCK: instrument shall operate properly after four drops from a height of four feet onto a hard wood floor.

OPERATOR USE, CARE AND MAINTENANCE OF THE DOSIMETER

5.34 *Maintenance.*—No maintenance should be performed by the user on the self-indicating electrostatic dosimeters.

5.35 *Care.*—When the instruments are received, the operator should check the ability to zero the dosimeter, check its response to radiation, and check its electrical leakage characteristics. When using the dosimeters, the operator should keep the hairline as close to zero as possible and should prevent the dosimeter from becoming contaminated. When not in use, the dosimeters should be charged and stored in a dry place.

5.36 Since most electrostatic dosimeters will require a "soak-in" charge after long-term storage in an uncharged condition, such dosimeters should be charged and the reading observed for a few hours before use. A second charging may be required before the instruments are ready for operation.

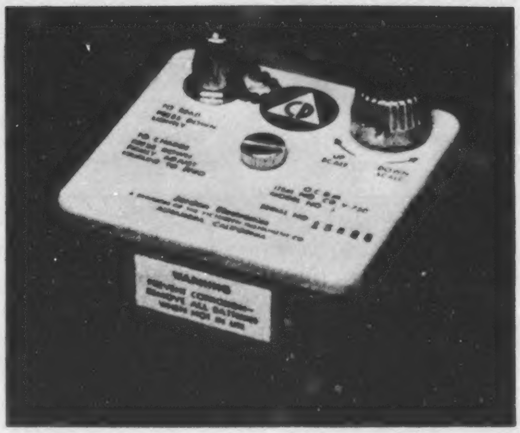

FIGURE 5.37.—CD V–750, dosimeter charger.

CD V–750

5.37 The CD V–750 dosimeter charger is used to read and charge self-indicating electrostatic dosimeters (Figure 5.37). A standard 1.5 volt flashlight cell is used as the source of electrical power.

IMPORTANT SPECIFICATIONS FOR THE CD V–750

1. LIGHT SOURCE: instrument must provide illumination for reading and/or charging the dosimeter.
2. TEMPERATURE: instrument shall operate properly from −20° F to +125° F.
3. PRESSURE: instrument shall operate properly from sea level to 25,000 feet.
4. SHOCK: instrument shall operate properly after 6 four-foot drops onto a hard wood floor.

OPERATOR USE, CARE AND MAINTENANCE OF THE CD V–750

5.38 *Batteries.*—The 1.5 volt flashlight cell should be replaced when the lamp dims noticeably on actuating the charging switch. Replace bad batteries in accordance with instructions in the instrument manual. WHENEVER THE INSTRU-

MENT IS STORED FOR MORE THAN A FEW WEEKS, THE BATTERY SHOULD BE REMOVED TO PREVENT POSSIBLE DAMAGE.

5.39 *Operations.*—To read a dosimeter, remove the dust cap from the charging contact, place the dosimeter on the charging contact, and press lightly to light the lamp. Read the dosimeter and replace the dust cover when finished. The dosimeter may also be read by holding it toward any light source sufficient to illuminate the hairline. To charge a dosimeter follow the procedure printed on the CD V-750.

CD V-457

5.40 The CD V-457 (Figure 5.40) is a Geiger counter which has been especially designed for classroom demonstration use. It operates on a normal 110 volt AC power supply and produces both visible and audible responses to nuclear radiation. The instrument is used in teaching basic nuclear radiation physics and for decontamination demonstrations.

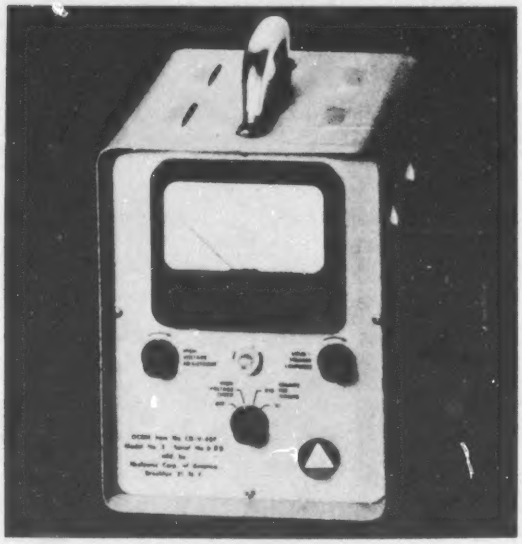

FIGURE 5.40.—CD V-457, classroom demonstration unit.

CD V-778

5.41 The CD V-778 30 millicurie Training Source Set consists of six Cobalt 60 sealed sources (Figure 5.41) and accessory equipment. It should be noted that this Training Source Set has been designed specifically for use in training exercises and is not intended as an accurate calibration source.

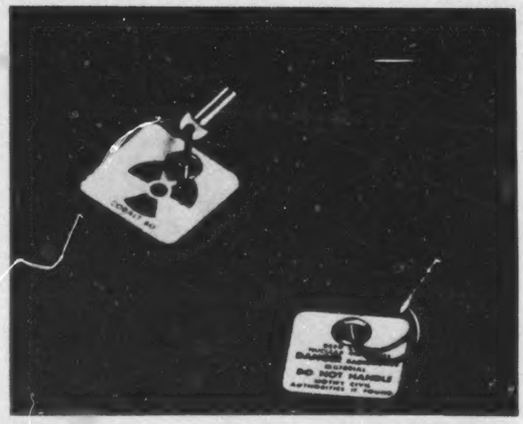

FIGURE 5.41.—Sealed source capsules, open and sealed.

5.42 The CD V-778 Training Source Set consists of the following items:

- 6—5.0 mCi Cobalt 60 Sealed Sources totaling 30 mCi, CD V-784
- 1—Lead Container, small (CD V-791)
- 1—Lead Container, medium (CD V-792)
- 2—Locks for Lead Container CD V-792
- 1—Long-Handled Tongs for Handling Sources (CD V-788)
- 8—Radiation Area Signs
- 2—0-200 mR Dosimeters (CD V-138)
- 1—Dosimeter Charger (CD V-750)
- 1—Geiger Counter (CD V-700)

CD V-794

5.43 The CD V-794 (Figure 5.43) is a calibration unit containing a Cesium 137 source of approximately 130 curies. The primary shield is composed of depleted uranium, and is shaped to beam the radiation from the radioactive cesium into a shielded exposure chamber. Interposed in the radiation beam path is an attenuator disk by means of which radiation levels of 0.4, 4, 40, and 400 R/hr are produced in the exposure chamber. Jigs are provided to

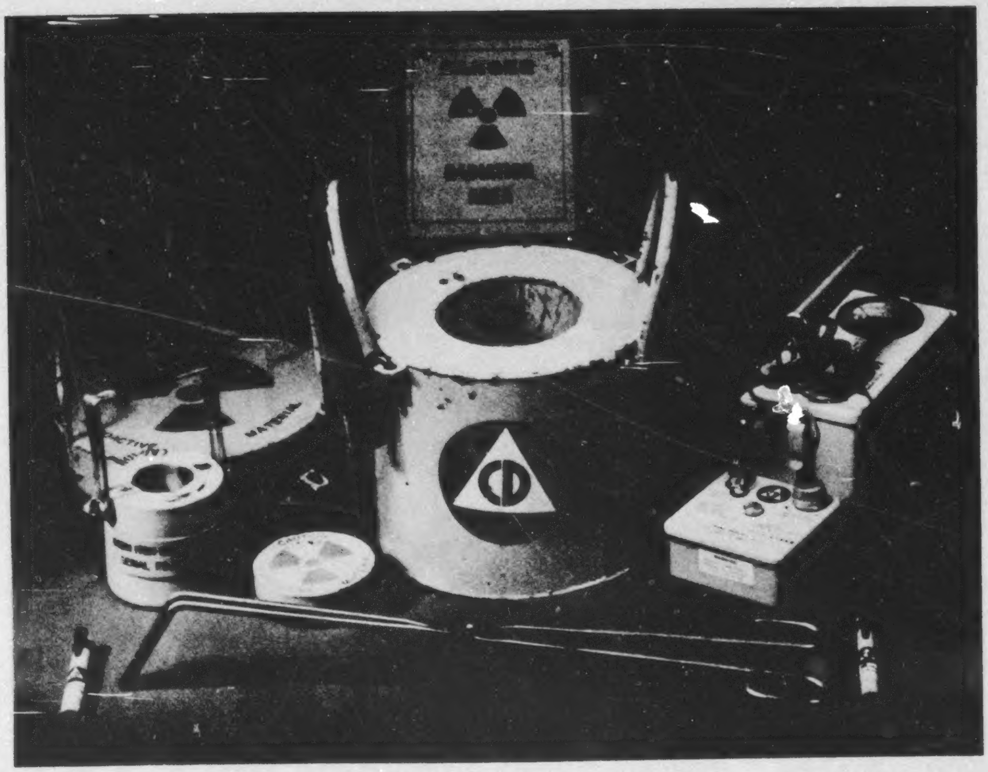

FIGURE 5.42.—CD V–778, Training Source Set.

properly position the instruments during calibration. The range switch and calibrating potentiometers are adjusted through flexible linkages leading outside of the exposure chamber. The unit is designed to provide suitable protection from radiation hazards to the operator.

CD V–757

5.44 The Barrier Shielding Demonstrator Set, CD V–757, is a low range radiation detection instrument coupled to a neon lighted remote readout indicator that is readily visible in large conference rooms or small auditoriums. With the large indicator, a lecturer can show how radiation from a radioactive source is affected by distance and shielding.

A small amount of cesium 137, which gives off gamma rays, is housed in a lead ball mounted in the demonstration platform. A hole in the platform leads to the cesium source, and gamma radiation is beamed vertically. The aperture is normally closed by a tungsten plug which is

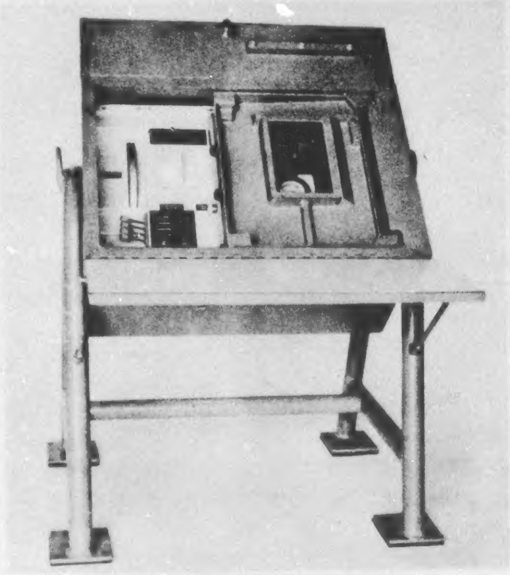

FIGURE 5.43.—CD V–794, calibration unit.

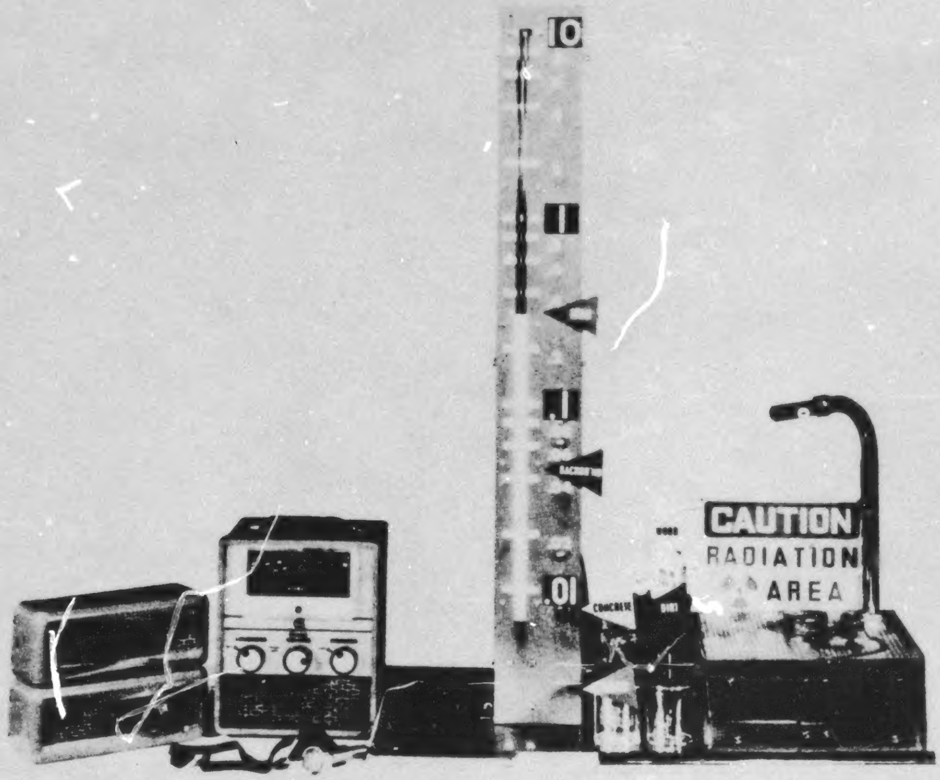

FIGURE 5.44.—CD V-757.

padlocked in position. Mounted directly over the hole is a Geiger Muller tube that is in the radiation beam when the tungsten plug is removed.

By placing a radiation absorbing material over the platform hole, the intensity of the radiation beam is attenuated, resulting in a lower exposure rate readout. Comparison of radiation absorbing materials can readily be made by placing them in the radiation beam.

The relatively simple mathematical relationship that exists for distances from a point source is demonstrated by doubling the distance between the detector and source, and observing the effect upon the radiation level on the large indicator.

CD V–781

5.45 The CD V–781, Aerial Survey Meter (Figure 5.45), is designed for limited postattack operational use in slow low-flying aircraft. The CD V–781 will be used by specially trained monitors. The four major components of the CD V–781 aerial survey set are: detector unit (three Geiger-Mueller tubes); metering unit with three range dials (0–0.1 R/hr, 0–1.0 R/hr, and 0–10 R/hr); simulator unit with dials corresponding to the metering unit; and a magnetic tape recorder.

IMPORTANT SPECIFICATIONS OF THE CD V–781

1. RANGE: 0–0.1, 0–1.0, and 0–10 roentgens per hour.
2. DETECTS: gamma radiation only.
3. ACCURACY: ±10% of true exposure rate from Cobalt 60 or Cesium 137.
4. CALIBRATION: is performed by the State maintenance shops.

5. **TEMPERATURE:** the instrument will operate from -20° F. to 110° F.
6. **HUMIDITY:** to 95%.
7. **ALTITUDE:** to 20,000 feet; preferably below 1,000 feet.
8. **OPERATING TIME:** 40 hours on nine flashlight batteries ("D" cells).
9. **TRACKING ERROR:** between the simulator dials and the metering dials shall not be more than 10%.
10. **READING TIME:** not less than 15 seconds—preferably 1 minute.
11. **SHOCK AND VIBRATION:** instrument is designed to withstand normal shock and vibration encountered in small aircraft operation.
12. **DETECTOR UNIT:** contains three Geiger-Mueller tubes similar to the CD V-700. The detector unit should be carefully handled when installing batteries.
13. **WARMUP TIME:** 2 minutes.

OPERATIONAL CHECK PROCEDURES

5.46 *Metering Unit.*—Prior to mounting the *metering unit* into the aircraft, the instrument should be operationally checked with the use of the *simulator unit.* The following procedures should be used:

1. Attach the cable of the *metering unit* to the connector provided on the *simulator unit.*
2. Position the power switch on the *metering unit* to "Battery" power position and allow the instrument a warmup period of at least 2 minutes.
3. By rotation of the meter-reading control knob on the *simulator unit,* check each of the three meters at half scale.
4. Starting with the metering control knob in the extreme counterclockwise position, slowly rotate the knob clockwise. The tracking error between the meters of the *simulator unit* and corresponding meters on the *metering unit* should be no more than 10% at any simulated exposure rate.

5.47 The audio output may be checked by plugging in the headset to the *metering unit.* The audio output should be from 225

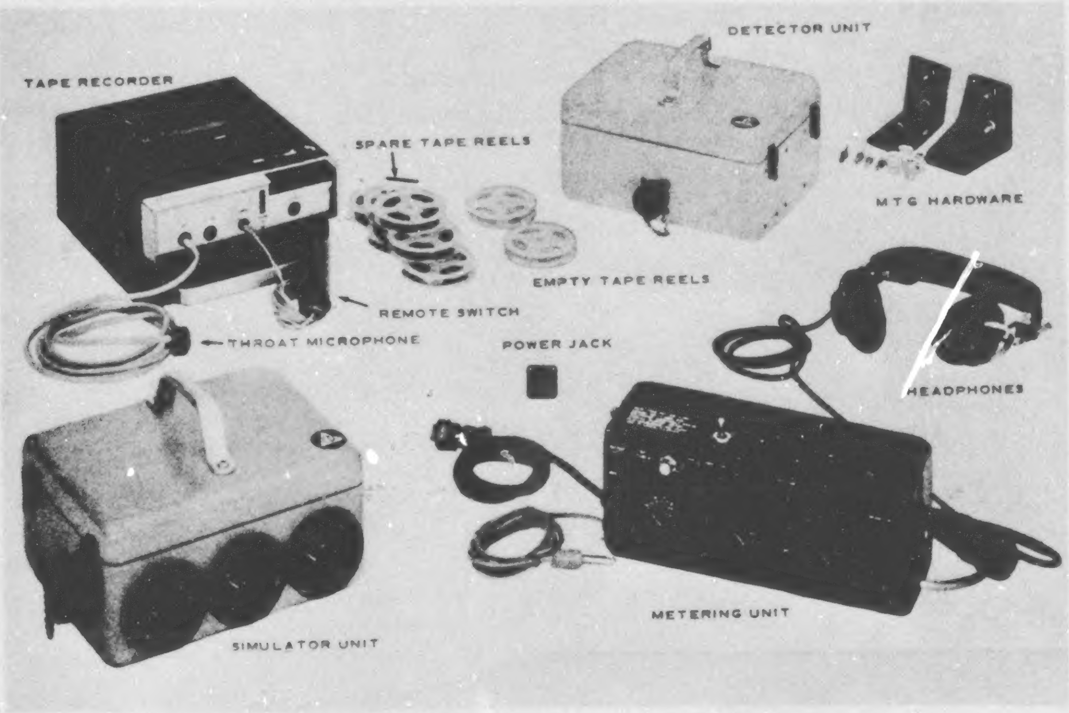

FIGURE 5.45.—Aerial survey meter, CD V-781, model 1

to 275 cycles per second (within one or two notes of middle C) for normal radiation background. The audio output can be operated with the *simulator unit*.

5.48 After installation of the CD V–781 Aerial Survey Meter into the aircraft, the operational check is performed as follows:

1. Instrument Battery Supply
   a. Observe meters prior to turning on instrument. Meters should indicate zero within one scale division (the instrument has no zero adjustment).
   b. Position the power switch on the *metering unit* to the "Battery" power switch position and allow the instrument a warmup period of at least 2 minutes.
   c. Observe the meters after warmup period. Meters should continue to indicate zero within one scale division when only normal background radiation is present. In the event external radiation from fallout prohibits this check, it should be assumed the instrument is operating properly if it indicates radiation levels above normal background.
   d. Press the "Battery Check" switch. The 0–0.1 R/hr meter should read at, or slightly above, the battery check point.
2. Aircraft Power Supply
   a. When the aircraft electrical power source is used, position the power switch on the *metering unit* to the "Plane" power position.
   b. Repeat steps c and d above.

THE TAPE RECORDER

5.49 The manufacturer's manual supplied with the recorder indicates precautions to be observed and provides detailed instructions for operation. A monitor expecting to use the recorder should practice using it until he is proficient both on the ground and in flight. The recording and playback of preliminary survey information will provide a check of the recorder's operability. Prior to a mission, the "Battery Voltage Indication" should be observed and batteries replaced, if required.

REFERENCES

Handbook for Radiological Monitors.—FG–E–5.9, April 1963. Instrument manuals accompanying each instrument.

Handbook for Aerial Radiological Monitors.—FG–E–5.9.1, July 1966.

RADIOACTIVE FALLOUT

Now we are ready for a closer look at our enemy—RADIOACTIVE FALLOUT. We have learned how it is produced through a nuclear detonation and we have learned how to measure it when it arrives. This prompts a question:

> Must we *wait* until fallout actually arrives before we can decide where it is going and what to do about it?

. . . and the answer is . . .

NO! ! !

True enough, we cannot detect nor can we measure fallout *before* it arrives but we definitely *do not have to just sit and wait for it.* Although it may appear that the fallout makes its own rules, its movement is affected by a number of elements, some of which we can measure. This lets us make predictions about the behavior of fallout, to estimate its location. In short, when we take our close look at fallout in this chapter, we will see how RADEF techniques can provide life-saving and morale-supporting warnings of the direction of fallout movement. We will see:

WHY	there is fallout
HOW	fallout is formed
HOW	it is spread
WHAT	influences that spread
WHERE	is fallout most likely to land
WHEN	to expect it

INTRODUCTION

6.1 "Fallout" is one of those words which define themselves. Say the word, and you have grasped its essential meaning; the fallback to earth of radioactive particles produced by the detonation of a nuclear weapon. It is only when we begin to learn more about fallout that we start to lose sight of this central and simple idea. Words like "clean bomb" and "dirty bomb"; "early fallout" and "worldwide fallout"; "fission products" and "fusion products"; "local fallout" and "late fallout"; "surface burst" and "air burst"; "strontium 90" and "carbon 14" make us wonder if we know what fallout is after all, despite that built in definition. So, let us look at these words and see what they mean.

SOURCES OF RADIOACTIVE MATERIAL

6.2 Let us first consider where the radioactive material in fallout comes from? How many sources are there and are all equally important?

6.3 When uranium or plutonium are fissioned the heavy atoms are split into smaller atoms and a vast amount of energy is released. Millions upon millions of these atomic nuclei are split or fissioned in the explosion of a nuclear weapon. About 200 different isotopes of about 35 elements are produced as fission products. Most of these are radioactive, decaying by emission of beta particles frequently accompanied by gamma radiation. These fission products constitute the largest single source of radioactive material in the fallout.

6.4 What about the radioactivity of the *fusion* products? The different fusion reactions used in fission—fusion type weapons may produce tritium (a radioactive hydrogen isotope) and the neutrons produced in the reaction may cause the formation of radioactive carbon (carbon 14) from the nitrogen in the air. However, the carbon 14 produced is small relative to that normally present in the atmosphere. Only insofar as possible genetic effects might theoretically be incurred over the next several thousand years could carbon 14 or tritium be considered possible hazards. Otherwise, fusion products are *neglected* as an important source of radioactive material contributing to the immediate postattack survival problem.

6.5[1] The uranium and plutonium which may have escaped fission in the nuclear weapon represent a further possible source of residual nuclear radiation. The fissionable isotopes of these elements emit alpha particles and also some gamma rays of low energy. However, because of their very long half-lives, the activity is very small compared with that of the fission products.

6.6 It will be seen later that the alpha particles from uranium and plutonium, or from radioactive sources in general, are completely absorbed in an inch or two of air. This, together with the fact that the particles cannot penetrate ordinary clothing, indicates that uranium and plutonium deposited on the earth do not represent a serious external hazard. Even if they actually come in contact with the body, the alpha particles emitted are unable to penetrate the unbroken skin.

6.7 The last source of radioactive material to be considered is the neutron induced activity. The neutrons liberated in the fission process, but which are not involved in the propagation of the fission chain, are ultimately captured by the weapon materials through which they must pass before they can escape, by nitrogen (especially) and oxygen in the atmosphere, and by various elements present in the earth's surface. As a result of capturing neutrons, substances may become radioactive. They, consequently, emit beta particles, frequently accompanied by gamma radiation, over an extended period of time following the explosion. Such neutron-induced activity, therefore, is part of the residual nuclear radiation.

6.8 The activity induced in the weapon materials is highly variable, since it is greatly dependent upon the design or structural characteristics of the weapon. Any radioactive isotopes produced by neutron capture in the residues will remain associated with the fission products. In the period from 20 hours to 2 weeks after the burst, depending to some extent upon the weapon materials, such isotopes, as uranium–237 and –239 and neptunium–239 and –240 can contribute up to 40 percent of the total activity of the weapon residues. At other times, their activity is negligible in comparison with that of the fission products.

6.9 An important contribution to the residual nuclear radiation can also arise from the activity induced by neutron capture in certain elements in the earth and in sea water. The extent of this radioactivity is highly variable. The element which probably deserves most attention, as far as environmental neutron-induced activity is concerned, is sodium. Although this is present only to a small extent in average soils, the amount of radioactive sodium–24 formed by neutron capture can be quite appreciable. This isotope has a half-life of 15 hours and emits both beta particles, and more important, gamma rays of relatively high energy.

6.10 How much radioactive material is available for distribution as fallout?

6.11 At 1 minute after a nuclear explosion, when the residual nuclear radiation has been postulated as beginning, the gamma-ray activity of the 2 ounces of *fission products* from a 1-kiloton fission yield explosion is comparable with that of about 30,000 tons of radium in equilibrium with its decay products. It is seen, therefore that for explosions in the megaton-energy range the amount of radioactivity produced is enormous. Even though there is a decrease from the 1-minute value by a factor of over 3,000 by the end of the day, the radiation intensity will still be large.

6.12 It has been calculated that if all the *fission products* from an explosion with a 1-megaton fission yield could be spread uniformly over a smooth area of 10,000 square miles, the radiation exposure rate after 24 hours would be 6 roentgens per hour at a level of 3 feet above the ground. In actual practice, a uniform distribution would be improbable, since a large proportion of the fission products would be deposited nearer ground zero than at farther distances. Hence, the radiation intensity will greatly exceed the average at points near the explosion center, whereas at much greater distances it will usually be less. The above example does not include any neutron induced activity.

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[1] Paragraphs 6.5 through 6.18 are reprints of selected paragraphs from The Effects of Nuclear Weapons.

FORMATION OF FALLOUT

6.13 In a surface burst, large quantities of earth or water enter the fireball at an early stage and are fused or vaporized. When sufficient cooling has occurred, the fission products and other radioactive residues become incorporated with the earth particles as a result of the condensation of vaporized fission products into fused particles of earth, etc. A small proportion of the solid particles formed upon further cooling are contaminated fairly uniformly throughout with radioactive fission products and other weapon residues, but in the majority the contamination is found mainly in a thin shell near the surface. In water droplets, the small fission product particles occur at discrete points within the drops. As the violent disturbance due to the explosion subsides, the contaminated particles and droplets gradually fall back to earth. This effect is referred to as the "fallout". It is the associated radioactivity in the fallout, which decays over a long period of time, that is the main source of residual nuclear radiations.

6.14 The extent and nature of the fallout can range between wide extremes. The actual behavior will be determined by a combination of circumstances associated with the energy yield and design of the weapon, the height of the explosion, the nature of the surface beneath the point of burst, and the meteorological conditions, which we will discuss later. In the case of an *air burst*, for example, occurring at an appreciable distance above the earth's surface, so that no surface materials are sucked into the cloud, negligible fallout is produced. Thus at Hiroshima and Nagasaki, where approximately 20-kiloton devices were exploded 1,850 feet above the surface, casualties due to fallout were completely absent.

6.15 On the other hand, a nuclear explosion occurring at or *near the earth's surface* can result in severe contamination by the radioactive fallout. In the case of the 15-megaton thermonuclear device tested at Bikini Atoll on March 1, 1954—the BRAVO shot of Operation CASTLE—the ensuing fallout caused substantial contamination over an area of more than 7,000 square miles. The contaminated region was roughly cigar-shaped and extended more than 20 statute miles upwind and over 320 miles downwind. The width in the crosswind direction was variable, the maximum being over 60 miles.

6.16 It should be understood that the fallout is a gradual phenomenon extending over a period of time. In the BRAVO explosion, for example, about 10 hours elapsed before the contaminated particles began to fall at the extremities of the 7,000 square mile area. By that time, the radioactive cloud had thinned out to such an extent that it was no longer visible. This brings up the important fact that fallout can occur even when the cloud cannot be seen. Nevertheless, the area of contamination which presents the most serious hazard generally results from the fallout of visible particles.

6.17 The fallout pattern from particles of visible size will have been established within about 24 hours after the burst. This is referred to as "early fallout" and is also sometimes called "local" or "close-in" fallout. In addition, there is the deposition of very small particles which descend very slowly over large areas of the earth's surface. This is the "delayed fallout," also referred to as "worldwide fallout," to which residues from nuclear explosions of various types—air, high-altitude, surface, and shallow subsurface—may contribute.

6.18 Although the test of March 1, 1954 produced the most extensive local fallout yet recorded, it should be pointed out that the phenomenon was not necessarily characteristic of (nor restricted to) thermonuclear explosions. It is very probable that if the same device had been detonated at an appreciable distance above the Coral Island, so that the large fireball did not touch the surface of the ground, the early fallout would have been of insignificant proportions.

WHAT GOVERNS THE LOCATION OF EARLY FALLOUT—

6.19 There are several factors governing the location of early fallout. These are:

1. Kind of weapon.
2. Yield of the burst.
3. Altitude of the burst.
4. Height and dimension of the cloud.
5. Distribution of radioactive particles within the cloud.
6. Radioactivity associated with various particle sizes.
7. Rate of fall of the particles.
8. Meteorological conditions, including wind structure to the top of the cloud and any type of precipitation.

6.20 These factors are so interrelated that it is almost impossible to isolate the effects of any one factor with precision. However, *it is* possible to discuss the general significance of each factor.

6.21 *Kind of Weapon.*—Since the fusion products do not make a significant contribution of radioactive material to fallout, even when the weapon is a thermonuclear one (i.e., fusion is involved), *only the fission yield of a given weapon is important in determining the total amount of radioactive fallout.* For example, although the total amount of radioactive material produced would be approximately the same in a 1 megaton 50% fission yield weapon and a 2 megaton 25% fission yield weapon, the resulting fallout patterns would probably differ because of the greater height obtained by the 2 megaton cloud.

6.22 *Altitude of the Burst (This is a crucial factor).*—The fraction of the total radioactivity of the bomb residues that appear in the early fallout depends upon the extent that the fireball touches the surface. Thus, the proportion of the available activity contributing to early fallout increases, as the height of burst decreases and more of the fireball comes into contact with the earth.

6.23 *Height and Dimension of the Cloud.*—It is obvious that the physical size of the cloud at the time of stabilization will have an effect on the distribution of early fallout. The height to which the individual particles are carried principally determines how far downwind a given particle size will drift, and the horizontal extent of the cloud affects the width of the area over which fallout will occur.

6.24 The eventual height reached by the nuclear cloud depends upon the energy of the bomb and upon the temperature and density of the surrounding air. The greater the amount of energy liberated the greater will usually be the upward thrust due to buoyancy and so the greater will be the distance the cloud ascends. It is probable, however, that the maximum height obtainable by the nuclear cloud is affected by the height of the tropopause, which is the boundary layer between the relatively stable air of the stratosphere and the more turbulent troposphere. (See Figure 6.24.)

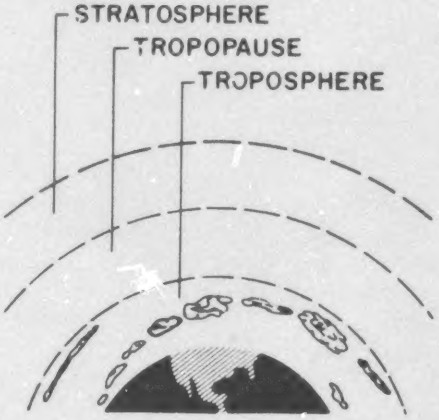

FIGURE 6.24.—The earth's atmosphere.

6.25 The height of the tropopause is usually slightly above 50,000 feet in the tropics and at 30,000 to 40,000 feet in middle latitudes in the summer. In winter, in the middle latitudes, it is somewhat lower on the average than in the summer. For smaller kiloton weapons the height of the tropopause generally limits the height of the nuclear cloud. Even for larger size

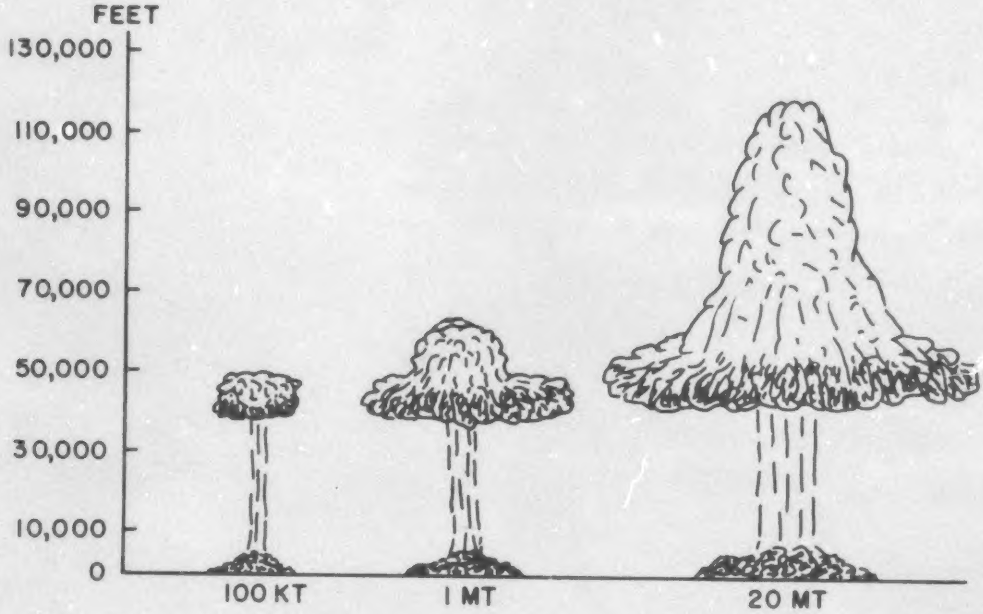

FIGURE 6.25.—Representative nuclear detonation cloud heights.

weapons in the megaton range, the development of the cloud slows down as the cloud builds up into the stratosphere. Thus the lower the tropopause, the less the total height of the cloud. Figure 6.25 illustrates rough estimates of some possible cloud heights under "typical" conditions.

6.26 *Distribution of Radioactivity within the clouds.*—Figure 6.26 summarizes the distribution of radioactivity within the nuclear cloud. You will note that approximately 90% of the total activity is located in the cloud and only 10% or less in the stem section with the bulk of the activity in the base of the cloud. It is further assumed that the bulk of the radioactive material that contributes to early fallout will be at or below about 80,000 feet. Above this altitude the particles will probably be in a finely divided state and will contribute most to the worldwide fallout.

6.27 *Amount of Radioactivity Associated with Various Particle Sizes.*—From experimental evidence radioactive particles are known to exist with diameters ranging from .01 to 1,000 microns (A micron is 1 millionth of a meter). It is quite possible that even smaller particles exist since the lower limit of this range is the limit of the resolving power of the electron microscope. To determine the fallout patterns from a nuclear detonation it is necessary to know the distribution of the total radioactivity among particles of various

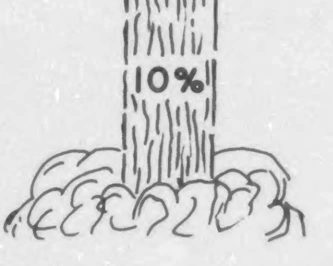

FIGURE 6.26.—Distribution of radioactivity.

sizes. Knowledge in this area is still rather limited because of the difficulty in obtaining large and representative samples of radioactive debris from a nuclear cloud.

6.28 *Rate of Fall of Particles.*—The particles carried up into the atmosphere by a nuclear detonation are acted upon by gravity and carried by the winds. Since wind directions and speeds usually vary from one level to another, each particle follows a constantly changing course, and changing speed as it falls to earth. The rate of fall depends upon the particle size, shape and weight and the characteristics of the air. The stronger the wind in each layer the further the particles will be car-

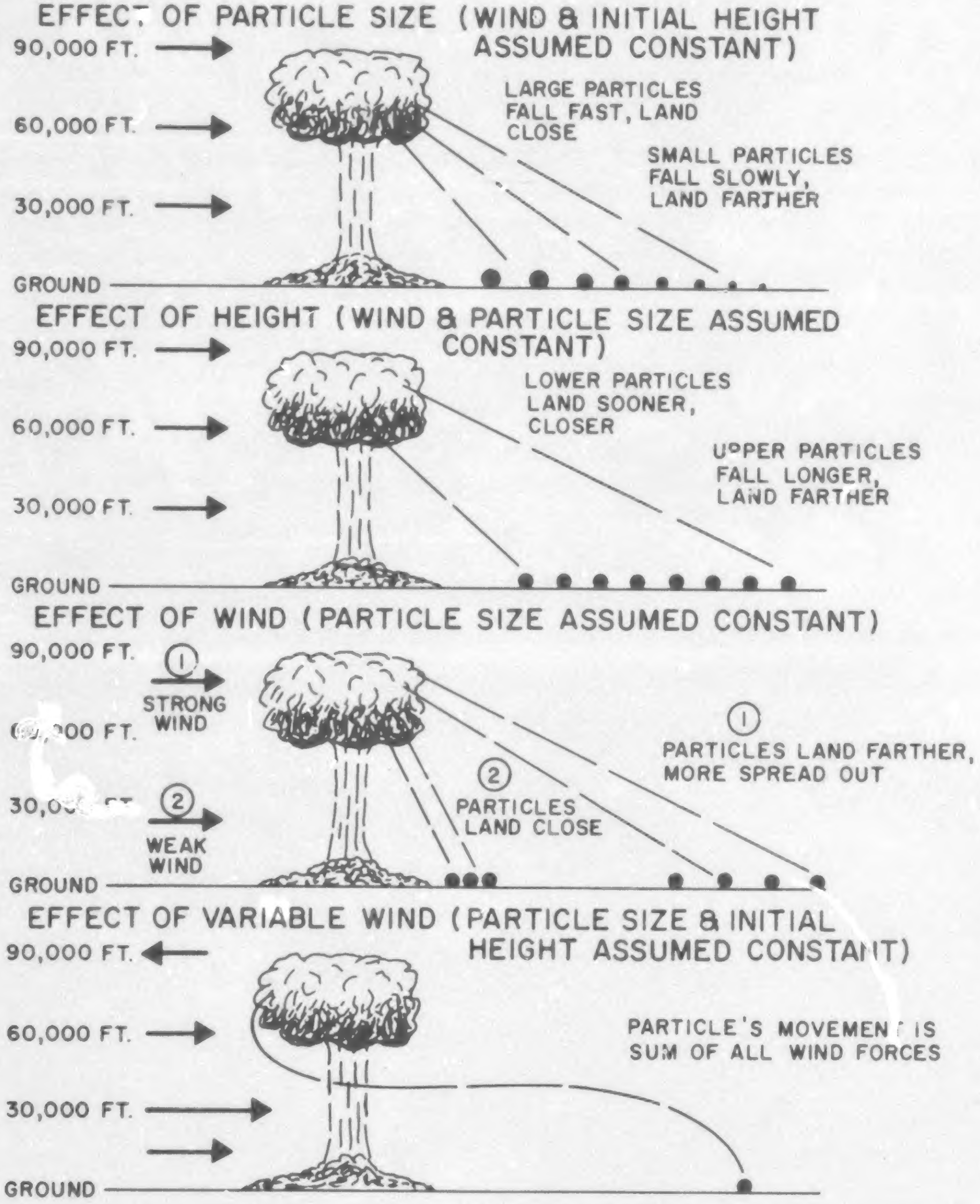
EFFECT OF PARTICLE SIZE (WIND & INITIAL HEIGHT ASSUMED CONSTANT)
90,000 FT.
60,000 FT.
30,000 FT.
GROUND
LARGE PARTICLES FALL FAST, LAND CLOSE
SMALL PARTICLES FALL SLOWLY, LAND FARTHER
EFFECT OF HEIGHT (WIND & PARTICLE SIZE ASSUMED CONSTANT)
90,000 FT.
60,000 FT.
30,000 FT.
GROUND
LOWER PARTICLES LAND SOONER, CLOSER
UPPER PARTICLES FALL LONGER, LAND FARTHER
EFFECT OF WIND (PARTICLE SIZE ASSUMED CONSTANT)
90,000 FT.
① STRONG WIND
60,000 FT.
30,000 FT.
② WEAK WIND
GROUND
①
PARTICLES LAND FARTHER, MORE SPREAD OUT
②
PARTICLES LAND CLOSE
EFFECT OF VARIABLE WIND (PARTICLE SIZE & INITIAL HEIGHT ASSUMED CONSTANT)
90,000 FT.
60,000 FT.
30,000 FT.
GROUND
PARTICLE'S MOVEMENT IS SUM OF ALL WIND FORCES

FIGURE 6.28.—Factors affecting distribution of radioactive particles.

ried in that layer. The faster the particle falls, the less influence the wind will have on it and the closer to ground zero it will land. The higher the altitude at which it begins to fall, the longer it will be carried by the wind, and under most conditions—when the winds at different altitudes do not oppose one another—the farther it will travel. (See figure 6.28.)

6.29 *Meteorological Conditions.*—Winds are the principal factor which affect the movement of the nuclear cloud. Even with the same type, yield, and altitude of detonation, different wind conditions will produce different fallout patterns of irregular shape. The speed and vertical shear of the upper air winds will also affect the concentration of radioactive material on the ground. A fallout pattern under conditions of strong winds aloft would differ from that of weak winds in two ways. First, the strong wind would spread the material over a larger area tending to reduce the concentration close to the source. Second, at a given distance the fallout would arrive sooner and would have had less time to decay.

6.30 The United States has a variety of upper air winds. During the winter, spring, and fall seasons the United States winds are primarily the "prevailing westerlies." By this it is meant that the winds over the United States blow more frequently from the western quarter than from any other quarters of the compass. The westerlies in the middle latitudes become increasingly predominant with increasing height up to about 40,000 feet. At 5,000 feet the winds are from the western quadrant about half the time; while at 30-40,000 feet they are from that quadrant about three-fourths of the time. Above 40,000 feet, the percentage of westerly winds again decreases.

6.31 The predominance of westerly wind direction changes with the seasons. Upper winds blow from the west more often during winter than during summer. The increase in frequency of other directions in the summer is more pronounced in the southeastern portion of the country, where directions become variable at all levels. Along the Pacific Coast, the winds blow less constantly from the west than in other sections of the country. Southwesterly and northwesterly winds are more common. Above 60,000 feet, easterly winds occur frequently in all seasons and are the rule in summer over most of the United States.

6.32 In describing direction of fallout from the point of detonation (GZ—ground zero), the terms "upwind" and "downwind" are often used. The "downwind" direction is the direction toward which the wind blows, while "upwind" means against the wind. When applied to fallout, the terms upwind and downwind will apply to the resultant or total effect of all the winds through which the particles have fallen. An upwind component results from the very rapid expansion of the cloud in all directions immediately after detonation. The disturbances at the time of the explosion will deposit radioactive material in upwind and crosswind directions for relatively short distances from ground zero.

6.33 Since the direction of fallout is determined by winds up to at least 80,000 feet, and since winds in the upper air frequently are quite different than winds at the surface, *surface wind directions cannot be used as an indication of direction of flow of high atmosphere winds.* It is not at all uncommon to have east, south, or north winds at the surface and westerly winds aloft.

6.34 In considering the possible area of fallout, *wind speed is as important as wind direction.* Depending on particle size, the direction determines the *sector to which they are carried*; and the *speed governs how far they will travel* before coming to the earth. Wind speeds over the United States generally are less in the summer than in winter at all heights and above all sections of the United States. The only exceptions would be during the passage of hurricanes or tornadoes which produce very strong surface winds in the warm seasons. This difference between seasons is greatest in the southeastern portion of the country, where winds become particularly light and variable in the summer. During the winter, upper winds along the Pacific Coast generally have lower speed than in any other section of the United

States. Wind speeds increase with altitude from the surface up to a level between 30,000 and 40,000 feet. Above this level they usually decrease in speed until at 60,000 to 80,000 feet they become relatively light.

6.35 The winds of greatest speed usually occur between 30,000 and 40,000 feet, winds exceeding 50 m.p.h. being the rule all over the country in winter and in the northeast in the summer. In this layer, winds greater than 100 m.p.h. are at times experienced over all areas of the United States, but have been observed most often over the northeast, where they are found about 25% of the time. In this northeastern area, winds of 200 m.p.h. occur frequently, with speeds of 300 m.p.h. observed on rare occasions. The high speed winds usually occur in narrow meandering currents within the broad belt of middle-latitude westerly winds, and are called "jet-streams".

6.36 The strongest winds encountered by a falling particle have the greatest proportional influence on its total movements. The strongest winds are usually at altitudes in the vicinity of *40,000 feet. These winds would largely determine the general direction and length of the fallout area*, although all the winds up to more than twice that height could be effective.

6.37 Fallout patterns over the United States would probably differ in shape and extent. In the northern half of the country considerably longer patterns would be expected, spreading toward the east because of the strong upper air westerly winds. The passage of low pressure areas would cause shifts from a more northeasterly to a more southeasterly spread of the fallout pattern from one day to another. In the summer, particularly in the southern part of the country, a great variety of patterns might be expected with a broad irregular spreading in all directions in some cases, and elongated streaks in others. It should be remembered also that *in an area where several target cities are situated within a few hundred miles of one another, fallout from more than one detonation might occur at the same place.*

6.38 Variation of the winds by day and night has little effect on factors that determine fallout patterns. Winds a few hundred feet aboveground frequently change from day to night, but those higher up, which have the greatest effect on the fallout pattern, do not follow a daily cycle. Cloudiness or fog alone are not believed to have a marked effect on fallout, although the combination of fallout particles with cloud droplets may result in a faster rate of fall. Some cloud types also have upward and downward air currents. The downward currents might tend to bring some of the radioactive debris down more rapidly than it would otherwise settle.

6.39 In addition to the wind, *precipitation* in a fallout area will affect the radioactive deposition. Rain drops and snow flakes collect a large proportion of the atmospheric impurities in their paths. Particles of radioactve debris are "washed" or "scrubbed" out of the air by precipitation. The result is that contaminated material, which would be spread over a much larger area by the slower dry weather fallout process, is rapidly brought down in local rain or snow areas. It is conceivable that hazardous conditions can occur in rain areas where ordinary fallout estimates might indicate a safe condition. This scrubbing reduces the amount of contamination left in the air to fall out farther downwind.

6.40 Terrain features will also cause a variation in the degree of deposition. Hills, valleys and slopes of a few hundred feet would probably not have a great effect on the fallout radiation levels. However, large mountains or ridges could cause significant variation in deposition by receiving more fallout on the sides facing the surface wind. This is true for both dry weather fallout and "rainout".

WORLDWIDE FALLOUT

6.41 Worldwide fallout by definition is much more widespread than early fallout. Worldwide fallout is that portion of the bomb residues which consists of very fine material that remains suspended in the air for times ranging from days to years.

These fine particles can be carried over la[illegible]eas by the wind and may ulti-m[illegible]e deposited on parts of the earth r[illegible] from the point of burst. It should no[illegible]e inferred from this term, however, that none of the fine material is deposited in areas near the explosions nor that such material is deposited uniformly over the earth.

6.42 You will recall that early fallout is important only when the nuclear burst occurs at or near the earth's surface so that a large amount of debris is carried up into the nuclear cloud. Contributions to worldwide fallout, however, can come from nuclear explosions of *all types*, except those so far beneath the surface that the ball of fire does not break through and there is no nuclear cloud, or those detonated in outer space. With regard to the mechanism of the worldwide fallout, a distinction must be drawn between the behavior of explosions of low energy yield and those of high energy yield. If the burst occurs in the lower part of the atmosphere the nuclear cloud from a detonation in the kiloton range will not generally rise above the top of the troposphere, consequently, nearly all the fine particles present in the bomb debris from such explosions will remain in the troposphere until they are eventually deposited.

6.43 The fine fallout particles from the troposphere are deposited in a complex way, complex, since various processes in addition to simple gravitational settling are involved. The *most important of these processes appears to be the scavenging effect of rain or other forms of moisture precipitation.* Almost all of the tropospheric fallout will be deposited within two to three months after the detonation so that bomb debris does not remain for very long in the troposphere.

6.44 While the fine debris is suspended in the troposphere the major part of the material is moved by the wind at high altitudes. In general, the wind pattern is such that the debris is carried rapidly in an easterly direction, making a complete circuit of the globe in some 4 to 6 weeks. Diffusion of the cloud to the north and south is relatively slow, with the result that most of the fine tropospheric fallout is deposited in a short period of weeks in a fairly narrow band and encircling the earth at the latitude of the nuclear detonation.

6.45 For explosions of high energy yield in the megaton range nearly all the bomb debris will pass up through the troposphere and enter the stratosphere. The larger particles will be deposited locally for a surface or sub-surface burst, while the very fine particles from bursts of all types can be assumed to be injected into the stratosphere. Due to their fineness and the absence of clouds and rainfall at such high altitudes, the particles will settle earthward very slowly. Although agreement does not exist as to the mechanism that produces observed differences in worldwide fallout, it is now clear that non-uniform circulation of stratospheric debris between the hemispheres is a characteristic of worldwide fallout. Also no agreement exists as to the residence time for worldwide fallout in the upper atmosphere, but it appears to be somewhere between 1 to 5 years.

6.46 During its long residence in the stratosphere, the bomb residues diffuse slowly but widely, so that they enter the troposphere at many points over the earth's surface. Once in the troposphere, fine material behaves like that which remained initially in that part of the atmosphere, and is brought to earth fairly rapidly by rain or snow.

6.47 An important feature of the stratospheric worldwide fallout is the fact that the radioactive particles are, in effect, stored in the stratosphere with a small fraction continuously dribbling down to the earth's surface. While in stratospheric storage, the debris does not represent a direct radioactive hazard. In fact, during this time most of the activity of the short-lived isotopes decays away and some of the activity of the longer-lived isotopes is appreciably reduced. Thus, stratospheric worldwide fallout is a slow, continuous non-uniform deposition of radioactive material over the entire surface of the earth, the rate of deposition depending on the total amount of bomb debris still present in the stratosphere, the season of the year and the amount of precipitation.

REPRESENTATION OF EARLY FALLOUT AREAS

6.48 In a somewhat idealized situation, it is to be expected that, except for the very smallest particles which descend over a wide area, the fallout of the larger particles fall to earth forming a kind of elongated (or cigar shaped) pattern of contamination. The shape and dimensions will be determined by the wind velocities and directions at all altitudes between the ground and the nuclear cloud. It should be emphasized that these elongated fallout patterns are idealized, and an actual fallout pattern will not conform to these patterns.

6.49 At a particular time after the detonation of a nuclear weapon, the radiation exposure rate is apt to be highest at ground zero, and will decrease as the distance from ground zero increases. This is because the amount of fallout per unit area is also likely to be less. There is another factor that contributes to this decrease in exposure rate with increasing distances from the explosion. This factor is time. The later times of arrival of the fallout at these greater distances mean that the fission products have *decayed* to some extent while the particles were suspended in the air.

6.50 Some idea of the manner in which a fallout pattern may develop over a large area during the period of several hours following a high-yield nuclear surface burst may be seen in Figure 6.50. For simplicity of representation, the actual complex wind pattern is replaced by an approximately equivalent or effective wind of 15 miles per hour. Figure 6.50 shows a number of contours for certain arbitrary exposure rates that could possibly have been observed on the ground at 1, 6 and 18 hours (H + 1; H + 6; H + 18) respectively after the explosion. It should be understood that the various exposure rates change *gradually* from one contour line to the next. Similarly, the last contour line shown does not represent the limit of contamination since the exposure rate will fall off steadily over a greater distance.

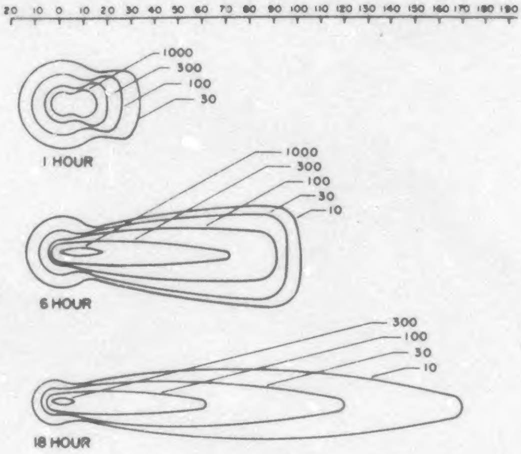

FIGURE 6.50.—Contours from fallout at 1, 6, and 18 hours after a surface burst with a fission yield in the megaton range (15 m.p.h. effective wind). Values given are in roentgens per hour.

6.51 *Consider first, a location 32 miles downwind from ground zero.*—At one hour after the detonation the observed exposure rate is seen to be about 30 R/hr; at 6 hours the exposure rate which lies between the contours for 1,000 and 300 R/hr has increased to about 800 R/hr; but at 18 hours it is down to roughly 200 R/hr. The increase in exposure rate from 1 to 6 hours means the fallout was not complete one hour after detonation. The decrease from 6 to 18 hours is then due to the natural decay of the fission products. On the other hand a total radiation exposure received at the given location at one hour after the explosion would be relatively small because the fallout has only just started to arrive. By 6 hours the total exposure could reach over 3,000 R and by 18 hours a total exposure of some 5,000 R could have accumulated. Subsequently, the total exposure would continue to increase but at a slower rate.

6.52 *Next, consider a point 100 miles downwind from ground zero.*—At one hour after the explosion the exposure rate, as indicated in Figure 6.50, is zero since the fallout will not have reached the specified location. At 6 hours the exposure rate is 10

R/hr and at 18 hours about 50 R/hr. The total (infinite) exposure will not be as great as at locations closer to ground zero because the quantity of fission products reaching the ground decreases at increasing distances from the explosion.

UNCERTAINTIES IN FALLOUT PREDICTIONS

6.53 Idealized fallout patterns are useful for planning purposes, but they are not blueprints of the actual fallout pattern that would occur. There are just too many uncertainties or variables involved in fallout, affecting both distribution of early fallout and rate of decrease of radioactivity, to make precise prediction possible.

6.54 It is difficult to estimate the extent of the induced radioactivity because of differences in type of weapon, the height of burst, and the nature of the soil or other material in which neutron bombardment has caused radioactivity. Furthermore, the existence of unpredictable hot spots will affect local radiation exposure rates, as will the nature of the terrain (buildings, trees, etc., may reduce the average radiation exposure rate above the ground to 70 or 75 percent of the value measured in open, flat terrain); weathering (wind may move surface-deposited fallout from one area to another or rain may wash it into the soil); fractionization (any one of several processes, apart from radioactive decay, that results in change in the composition of the radioactive weapon debris); fission products of differing ages and other factors. These uncertainties or variables mean that the cigar-shaped fallout patterns are *idealized*, not necessarily real. To see how the idealized pattern differs from an actual pattern, refer to Figures 6.54a through 6.54c which show fallout patterns from actual test detonations at the Nevada Test Site. These patterns were developed from monitored readings taken shortly after the test shots.

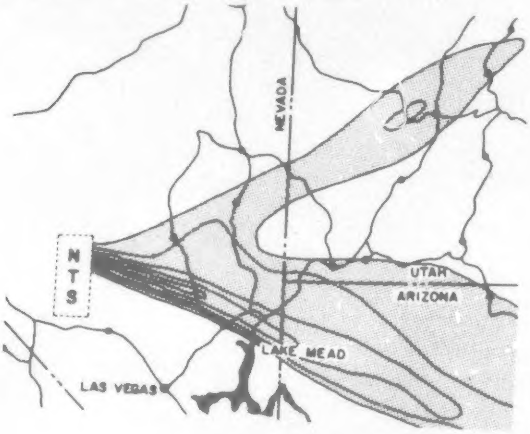

FIGURE 6.54a.—Fallout patterns from nuclear test detonation at the Nevada Test Site.

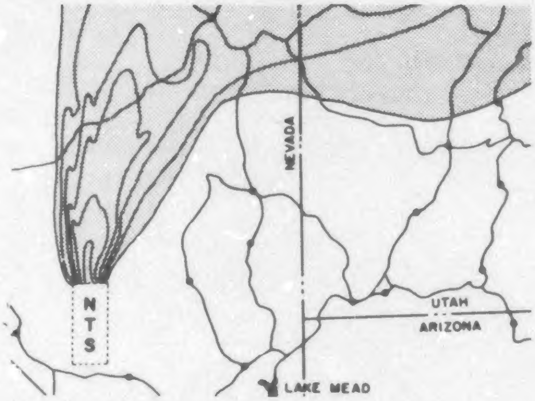

FIGURE 6.54b.—Fallout patterns from nuclear test detonation at the Nevada Test Site.

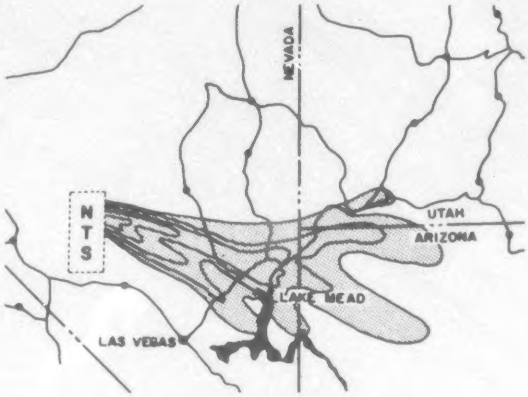

FIGURE 6.54c.—Fallout patterns from nuclear test detonation at the Nevada Test Site.

6.55 So far we have examined the fallout problem in general terms without trying to show the magnitude of the situation that could exist if the entire nation should be attacked. The map in Figure 6.55a illustrates an assumed *hypothetical* nuclear attack. Each circle represents a 20 megaton surface explosion. There are 50 of these. Each square represents a 10 megaton surface burst. There are 100 of these. Each triangle represents a 5 megaton burst and there are also 100 of these. In this hypothetical attack there are 250 weapons dropped on 144 different targets which include military, industrial and population objectives. The total yield of these 250 weapons is equivalent to 2500 megatons or *2.5 billion tons of TNT*!

6.56 Figure 6.55b shows the area that would be affected by fallout and the theoretical levels of radiation one hour after the attack. The fallout areas would be 30 to 50 miles long, depending upon wind speed and in the center of these areas the levels of radiation could be greater than 3,000 R/hr at H + 1.

6.57 Figure 6.55c illustrates the situation 6 hours after attack. Fallout would have spread over about 40% of the national land area. However, the radiation levels would have decayed by approximately a factor of ten. The exposure rates in these areas would range from one R/hr along the border to perhaps 400 R/hr in the center. Figure 6.55d illustrates the areas that would be affected by fallout one day after attack. Approximately 70% of the country's total area would be covered by fallout exposure rates greater than 0.2 R/hr. About 18% of the land area would have a very serious fallout condition.

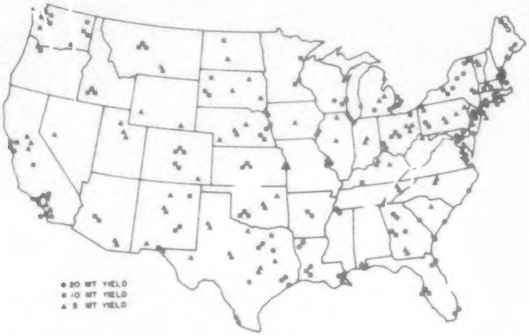

FIGURE 6.55a.—Hypothetical attack pattern.

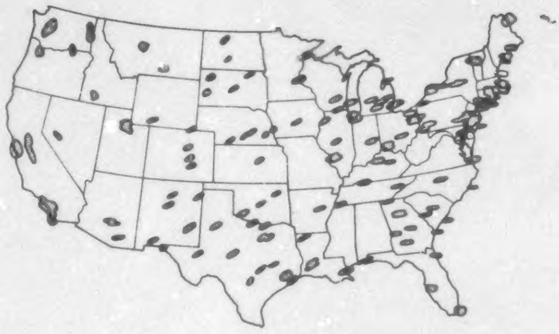

FIGURE 6.55b.—Hypothetical attack, H +1 situation. Exposure rates exceed 10 R/hr.

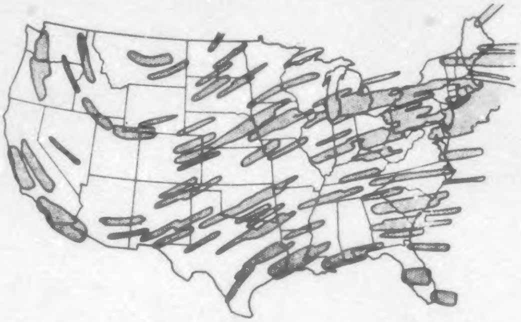

FIGURE 6.55c.—Hypothetical attack, H +6 situation. Exposure rates exceed 1 R/hr.

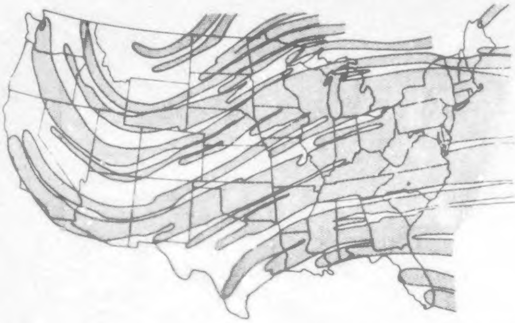

FIGURE 6.55d.—Hypothetical attack, H +24 sitaution. Exposure rates exceed .2 R/hr.

6.58 Shortly after the first day radioactive decay would begin to predominate over further deposition of fallout. The boundaries of these fallout areas would gradually shrink.

Figure 6.55e illustrates the situation one week after attack during which time the radioactive areas would have been decreasing in size and the exposure rates decreasing as a result of decay. Only about one-third of the nation's area would be

GENETIC EFFECT: The effect (of nuclear radiation, in particular) of producing changes (mutations) in the hereditary components (genes) in the germ cells present in the reproductive organs (gonads). A mutant gene causes changes in the next generation which may or may not be apparent.

GEOMETRY SHIELDING: Shielding gained by distance from the source of radiation.

GRAM: A unit of mass and weight in the metric system equal to approximately one-thirtieth of an ounce.

GROUND ZERO: The point on the surface of land or water vertically below or above the center of a burst of a nuclear (or atomic) weapon; frequently abbreviated to GZ. For a burst over or under water, the term surface zero should preferably be used.

GUN-TYPE WEAPON: A device in which two or more pieces of fissionable material, each less than a critical mass, are brought together very rapidly so as to form a supercritical mass which can explode as the result of a rapidly expanding fission chain.

H

HALF-LIFE: The time required for the activity of a given radioactive species to decrease to half of its initial value due to radioactive decay. The half-life is a characteristic property of each radioactive species and is independent of its amount or condition. The effective half-life of a given isotope is the time in which the quantity in the body will decrease to half as a result of both radioactive decay and biological elimination.

HALF-VALUE THICKNESS: The thickness of a given material which will absorb half the gamma radiation incident upon it. This thickness depends on the nature of the material—it is roughly inversely proportional to its density—and also on the energy of the gamma rays.

HALOGEN: The family of elements containing fluorine, chlorine, bromine, iodine and astatine.

HEAVY HYDROGEN: See *Deuterium*.

HEAVY WATER: Water containing heavy hydrogen (deuterium) atoms in place of the normal hydrogen atoms.

HIGH-ALTITUDE BURST: This is defined, somewhat arbitrarily, as a detonation at an altitude over 100,000 feet. Above this level the distribution of the energy of the explosion between blast and thermal radiation changes appreciably with increasing altitude due to changes in the fireball phenomena.

HOT SPOT: Region in a contaminated area in which the level of radioactive contamination is somewhat greater than in neighboring regions in the area. See *Contamination*.

HYDROGEN BOMB (OR WEAPON): A term sometimes applied to nuclear weapons in which part of the explosive energy is obtained from nuclear fusion (or thermonuclear) reactions. See *Fusion, Nuclear Weapon, Thermonuclear*.

I

IMPLOSION WEAPON: A device in which a quantity of fissionable material, less than a critical mass, has its volume suddenly decreased by compression, so that it becomes supercritical and an explosion can take place. The compression is achieved by means of a spherical arrangement of specially fabricated shapes of ordinary high explosive which produce an inwardly directed implosion wave, the fissionable material being at the center of the sphere. See *Supercritical*.

INDUCED RADIOACTIVITY: Radioactivity produced in certain materials as a result of nuclear reactions, particularly the capture of neutrons, which are accompanied by the formation of unstable (radioactive) nuclei. The activity induced by neutrons from a nuclear (or atomic) explosion in materials containing the elements sodium, manganese, silicon, or aluminum may be significant.

INFRARED: Electromagnetic radiations of wavelength between the longest visible red (7,000 Angstroms or 7×10^{-4} millimeter) and about 1 millimeter. See *Electromagnetic Radiation.*

INITIAL NUCLEAR RADIATION: Nuclear radiation (essentially neutrons and gamma rays) emitted from the fireball and the cloud column during the first minute after a nuclear (or atomic) explosion. The time limit of one minute is set, somewhat arbitrarily, as that required for the source of part of the radiations (fission products, etc., in the radioactive cloud) to attain such a height that only insignificant amounts reach the earth's surface. See *Residual Nuclear Radiation.*

INTENSITY: The energy (of any radiation) incident upon (or flowing through) unit area, perpendicular to the radiation beam, in unit time. The intensity of thermal radiation is generally expressed in calories per square centimeter per second falling on a given surface at any specified instant. As applied to nuclear radiation, the term intensity is sometimes used, rather loosely, to express the exposure rate at a given location, e.g, in roentgens (or milliroentgens) per hour.

INTERNAL RADIATION: Nuclear radiation (alpha and beta particles and gamma radiation) resulting from radioactive substances in the body. Important sources are iodine 131 in the thyroid gland, and strontium 90 and plutonium 239 in the bone.

INVERSE SQUARE LAW: The law which states that when radiation (thermal or nuclear) from a point source is emitted uniformly in all directions, the amount received per unit area at any given distance from the source, assuming no absorption, is inversely proportional to the square of that distance.

IONIZATION: The separation of a normally electrically neutral atom or molecule into electrically charged components. The term is also employed to describe the degree or extent to which this separation occurs. In the sense used in this book, ionization refers especially to the removal of an electron (negative charge) from the atom or molecule, either directly or indirectly, leaving a positively charged ion. The separated electron and ion are referred to as an ion pair. See *Ionizing Radiation.*

ION PAIR: See *Ionization.*

IONIZING RADIATION: Electromagnetic radiation (gamma rays or X-rays) or particulate radiation (alpha particles, beta particles, neutrons, etc.) capable or producing ions, i.e., electrically charged particles, directly or indirectly, in its passage through matter.

ISOCROME: A line connecting those points on the earth at which fallout from any one weapon is forecast to reach the surface at the same time.

ISOTOPES: Forms of the same element having identical chemical properties but differing in their atomic masses (due to different numbers of neutrons in their respective nuclei) and in their nuclear properties, e.g., radioactivity, fission, etc. For example, hydrogen has three isotopes, with masses of 1 (hydrogen), 2 (deuterium), and 3 (tritium) units, respectively. The first two of these are stable (nonradioactive), but the third (tritium) is a radioactive isotope. Both of the common isotopes of uranium, with masses of 235 and 238 units, respectively, are radioactive, emitting alpha particles, but their half-lives are different. Furthermore, uranium 235 is fissionable by neutrons of all energies, but uranium 238 will undergo fission only with neutrons of high energy. See *Nucleus.*

J

(None)

K

KILO-ELECTRON VOLT (keV): An amount of energy equal to 1,000 electron volts. See *Electron Volt.*

KILOTON ENERGY (KT): The energy of a nuclear (or atomic) explosion which is equivalent to that produced by the explosion of 1 kiloton (i.e., 1,000 tons) of TNT, i.e., 10^{12} calories of 4.2×10^{19} ergs. See *Megaton Energy, TNT Equivalent.*

L

LD/50 or LD–50 or LD_{50}: Abbreviations for median lethal dose. See *Median Lethal Dose.*

M

MACH EFFECT: See *Mach Stem.*

MACH STEM: The shock front formed by the fusion of the incident and reflected shock fronts from an explosion. The term is generally used with reference to a blast wave, propagated in the air, reflected at the surface of the earth. The Mach stem is nearly perpendicular to the reflecting surface and presents a slightly convex (forward) front. The Mach stem is also called the Mach front.

MALAISE: Uneasiness. Discomfort.

MASS: A measure of the quantity of matter. The material equivalent of energy. Mass and energy are different forms of the same thing.

MASS NUMBER: See *Nucleus.*

MEDIAN LETHAL DOSE: The amount of ionizing (or nuclear) radiation exposure over the whole body which, it is expected, would be fatal to 50 percent of a large group of living creatures or organisms. It is commonly (although not universally) accepted that about 450 roentgens, received over the whole body in the course of a few days or less, is the median lethal dose for human beings.

MEGACURIE: One million curies. See *Curie.*

MEGATON ENERGY (MT): The energy of a nuclear explosion which is equivalent to 1,000,000 tons (or 1,000 kilo-tons) of TNT, i.e., 10^{15} calories or 4.2×10^{22} egs. See *TNT Equivalent.*

MEV (MeV): Million electron volts, a unit of energy commonly used in nuclear physics. It is equivalent to 1.6×10^{-6} erg. Approximately 200 MeV of energy are produced for every nucleus that undergoes fission. See *Electron Volt.*

MICROCURIE: A one-millionth part of a curie. See *Curie.*

MICRON: A one-millionth part of a meter, i.e., 10^{-6} meter or 10^{-4} centimeter; it is roughly four one-hundred-thousandths (4×10^{-5}) of an inch.

MICROSECOND: A one-millionth part of a second.

MILLICURIE (mCi): A one-thousandth part of a curie.

MILLIREM: A one-thousandth part of a rem.

MILLIROENTGEN (mR): A one-thousandth part of a roentgen.

MILLISECOND: A one-thousandth part of a second.

MITOSIS: The process by which living cells multiply in the body by splitting or fissioning.

MOLECULE: The smallest unit of a chemical compound. For example a molecule of water consists of two hydrogen atoms combined with one atom of oxygen (H_2O), and a molecule of sugar consists of a combination of twelve carbon atoms, twenty-two hydrogen atoms, and eleven oxygen atoms ($C_{12}H_{22}O_{11}$).

MONITOR: An individual trained to measure, record, and report radiation exposure and exposure rates; provide limited field guidance on radiation hazards associated with operations to which he is assigned; and perform operator's maintenance of radiological instruments.

MONITORING: The procedure or operation of locating and measuring radioactive contamination by means of survey instruments which can detect and measure ionizing radiations. The individual performing the operation is called a monitor.

MUTATION: A change in the characteristics of an organism produced by altering the usual hereditary pattern. Radiation can cause mutations in all living things.

N

NEGATIVE PHASE: See *Shock Wave.*

NEUTRON: A neutral particle, i.e., with no electrical charge, of approximately unit mass, present in all atomic nuclei, except those of ordinary (light) hydrogen. Neutrons are required to initiate the fission process, and large numbers of neutrons are produced by both fission and fusion reactions in nuclear explosions.

NUCLEAR FISSION: See *Fission*.

NUCLEAR RADIATION: Particulate and electromagnetic radiation emitted from atomic nuclei in various nuclear processes. The important nuclear radiations, from the weapons standpoint, are alpha and beta particles, gamma rays, and neutrons. All nuclear radiations are ionizing radiations, but the reverse is not true; X-rays, for example, are included among ionizing radiations, but they are not nuclear radiations since they do not originate from atomic nuclei. See *Ionizing Radiation, X-Rays*.

NUCLEAR REACTOR: An apparatus in which nuclear fission is sustained in a *regulated* self-supporting chain reaction.

NUCLEAR WEAPON (OR BOMB): A general name given to any weapon in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion or both. Thus, the A- (or atomic) bomb and the H- (or hydrogen) bomb are both nuclear weapons. It would be equally true to call them atomic weapons, since it is the energy of atomic nuclei that is involved in each case. However, it has become more-or-less customary, although it is not strictly accurate, to refer to weapons in which all the energy results from fission as A-bombs or atomic bombs. In order to make a distinction, those weapons in which part, at least, of the energy results from thermonuclear (fusion) reactions among the isotopes of hydrogen have been called H-bombs or hydrogen bombs.

NUCLEON: The common name for a constituent particle of a nucleus such as a proton or neutron.

NUCLEUS (OR ATOMIC NUCLEUS): The small, central, positively charged region of an atom which carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which is a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or atomic number; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons, called the mass number, is closely related to the mass (or weight) of the atom. The nuclei of isotopes of a given element contain the same number of protons, but different numbers of neutrons. They thus have the same atomic number, and so are the same element, but they have different mass numbers (and masses). The nuclear properties, e.g., radioactivity, fission, neutron capture, etc., of an isotope of a given element are determined by both the number of neutrons and the number of protons. See *Atom, Element, Isotope, Neutron, Proton*.

NUDET: Report of nuclear detonation.

O

ORGAN: Organized group of tissue having one or more definite functions to perform in a living body.

OUTSIDE/INSIDE RATIO (OI): The measured ratio of the fallout gamma radiation exposure rate at some point outside a shelter to the exposure rate at some point inside the shelter. For radiological defense purposes, the specific outside point selected should have minimal protection. (See Protection Factor.)

OVERPRESSURE: The transient pressure, usually expressed in pounds per square inch, exceeding the ambient pressure, manifested in the shock (or blast) wave from an explosion. The variation of the overpressure with time depends on the energy yield of the explosion, the distance from the point of burst, and the medium in which the weapon is detonated. The peak overpressure is the maximum value of the overpressure at a given location and is generally experienced at the instant the shock (or blast) wave reaches that location. See *Shock Wave.*

P

PAIR PRODUCTION: The process whereby a gamma-ray (or X-ray) photon, with energy in excess of 1.02 MeV. in passing near the nucleus of an atom is converted into a positive electron and a negative electron. As a result, the photon ceases to exist. See *Photon.*

PEAK OVERPRESSURE: The maximum overpressure value at the blast front.

PERIODIC TABLE: A chart showing the arrangement of chemical elements in order of increasing atomic number in addition to grouping according to certain chemical similarities.

PERSONNEL EXPOSURE MEASUREMENTS: The measured exposure received by shelter occupants and operations personnel in the field.

PHOTOELECTRIC EFFECT: The process whereby a gamma-ray (or X-ray) photon, with energy somewhat greater than that of the binding energy of an electron in an atom, transfers all its energy to the electron which is consequently removed from the atom. Since it has lost all its energy, the photon ceases to exist. See *Photon.*

PHOTON: A unit or "particle" of electromagnetic radiation, possessing a quantum of energy which is characteristic of the particular radiation. If v is the frequency of the radiation in cycles per second and λ is the wave length in centimeters, the energy quantum of the photon in ergs is hv or $hc\lambda$ where h is Planck's constant, 6.62×10^{-27} erg-second and c is the velocity of light (3.00×10^{10} centimeters per second). For gamma rays, the photon energy is usually expressed in million electron volt (MeV) units, i.e., $1.24 \times 10^{-10}\lambda$ where λ is in centimeters or $1.24 \times 10^{-2}/\lambda$ if λ is in Angstroms.

PIG: A container (usually lead) used to transport and store radioactive materials. The thick walls protect the person handling the container from nuclear radiation.

PLUTONIUM: (Chemical symbol Pu.) A manmade transuranium element, atomic number 94. When uranium 238 is bombarded with neutrons in an atomic reactor some of the uranium is converted by nuclear reactions into plutonium, a fissionable material.

POINT SOURCE: A point at which radioactivity is concentrated as opposed to an area over which radioactive material might be spread. The DCPA Training Source Set sealed capsule is an example of a point source.

POSITRON: Positively charged electron.

POSITIVE PHASE: See *Shock Wave.*

PROTECTION FACTOR (PF): The ratio of gamma radiation exposure at a Standard Unprotected Location to exposure at a protected location, such as a fallout shelter. The Standard Unprotected Location is defined as a point 3 feet above an infinite, smooth, ground plane uniformally covered with fallout. Protection factor is a calculated value suitable for planning purposes as an indicator of relative protection. (See Outside/Inside Ratio.)

PROTON: A particle of mass (approximately) unity carrying a unit positive charge; it is identical physically with the nucleus of the ordinary (light) hydrogen atom. All atomic nuclei contain protons. See *Nucleus.*

Q

(None)

R

RAD: A unit of absorbed dose of radiation; it represents the absorption of 100 ergs of nuclear (or ionizing) radiation per gram of the absorbing material or tissue.

RADEF: Radiological Defense.

RADIOACTIVE CLOUD: An all-inclusive term for the mixture of hot gases, smoke, dust, and other particulate matter from the weapon itself and from the environment, which is carried aloft in conjunction with the rising fireball produced by the detonation of a nuclear weapon.

RADIOACTIVITY: The spontaneous disintegration of unstable nuclei with the resulting emission of nuclear radiation.

RADIATION EXPOSURE RECORD: The card issued to individuals for recording their personal radiation exposures.

RADIATION INJURY: The harmful effects caused by ionizing radiation.

RADIOLOGICAL DEFENSE: The organized effort, through warning, detection, and preventive and remedial measures, to minimize the effect of nuclear radiation on people and resources.

RBE (RELATIVE BIOLOGICAL EFFECTIVENESS): The ratio of the number of rads of gamma radiation of a certain energy which will produce a specified biological effect to the number of rads of another radiation required to produce the same effect is the RBE of this latter radiation.

REM: A unit of biological dose of radiation; the name is derived from the initial letters of the term "roentgen equivalent man (or mammal)." See *RAD*.

REMEDIAL MOVEMENT: Movement of people postattack to a less contaminated area or a better protected location.

REP: A unit of absorbed dose of radiation now being replaced by the rad; the name rep is derived from the initial letters of the term "roentgen equivalent physical." Basically, the rep was intended to express the amount of energy absorbed per gram of soft tissue as a result of exposure to 1 roentgen of gamma (or X-) raidation. This is estimated to be about 97 ergs, although the actual value depends on certain experimental data which are not precisely known. The rep is thus defined, in general, as the dose of any ionizing radiation which results in the absorption of about 97 ergs of energy per gram of soft tissue. For soft tissue, the rep and the rad are essentially the same. See *RAD*, *Roentgen*.

RESIDUAL NUCLEAR RADIATION: Nuclear radiation, chiefly beta particles and gamma rays, which persists for some time following a nuclear (or atomic) explosion. The radiation is emitted mainly by the fission products and other bomb residues in the fallout, and to some extent by earth and water constituents, and other materials, in which radioactivity has been induced by the capture of neutrons. See *Fallout*, *Induced Radioactivity*, *Initial Nuclear Radiation*.

ROENTGEN (R): A unit of exposure to gamma (or X-) radiation. It is defined precisely as the quantity of gamma (or X-) radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit quantity of electricity of either sign. From the accepted value (34 electron volts) for the energy lost by an electron in producing a positive-negative ion pair in air, it is estimated that 1 roentgen of gamma (or X-) radiation, would result in the absorption of about 87 ergs of energy per gram of air.

S

SHELTER: A habitable structure or space stocked with essential provisions and used to protect its occupants from fallout radiation.

SHIELDING: Any material or obstruction which absorbs radiation and thus tends to protect personnel or materials from the effects of a nuclear explosion. A moderately thick layer of any opaque material will provide satisfactory shielding from thermal radiation, but a considerable thickness of material of high density may be needed for nuclear radiation shielding.

SHOCK WAVE: A continuously propagated pressure pulse (or wave) in the surrounding medium which may be air, water, or earth, initiated by the expansion of the hot gases produced in an explosion. A shock wave in air is generally referred to as a blast wave, because it resembles and is accompanied by strong, but transient, winds. The duration of a shock (or blast) wave is distinguished by two phases. First there is the positive (or compression) phase during which the pressure rises very sharply to a value that is higher than ambient and then decreases rapidly to the ambient pressure. The positive phase for the dynamic pressure is somewhat longer than for overpressure, due to the momentum of the moving air behind the shock front. The duration of the positive phase increases and the maximum (peak) pressure decreases with increasing distance from an explosion of given energy yield. In the second phase, the negative (or suction) phase, the pressure falls below ambient and then returns to the ambient value. The duration of the negative phase is approximately constant throughout the blast wave history and may be several times the duration of the positive phase. Deviations from the ambient pressure during the negative phase are never large and they decrease with increasing distance from the explosion. See *Dynamic Pressure, Overpressure.*

SOMATIC: Of or relating to the body, as opposed to the spirit; physical.

SPECTRUM: An image, visible or invisible, formed by rays of light or other radiant energy, in which parts are arranged according to their refrangibility or wave-length, so that all of the same wave-length fall together while those of different wave-lengths are separated from each other, forming a regular progressive series.

STRATOSPHERE: A relatively stable layer of the atmosphere between the tropopause and a height of about 30 miles in which the temperature changes very little (in polar and temperate zones) or increases (in the tropics) with increasing altitudes. In the stratosphere clouds of water never form and there is practically no convection. See *Tropopause, Troposphere.*

SUBCRITICAL: The inability of a fissionable material to support a self-sustained chain reaction.

SUBSURFACE BURST: See *Underground Burst, Underwater Burst.*

SUPERCRITICAL: A term used to describe the state of a given fission system when the quantity of fissionable material is greater than the critical mass under the existing conditions. A highly supercritical system is essential for the production of energy at a very rapid rate so that an explosion may occur. See *Critical Mass.*

SURFACE BURST: The explosion of a nuclear (or atomic) weapon at the surface of the land or water or at a height above the surface less than the radius of the fireball at maximum luminosity (in the second thermal pulse). An explosion in which the weapon is detonated actually on the surface (or within $5W^{0.3}$ feet, where W is the explosion yield in kilotons, above or below the surface) is called a contact surface burst or a true surface burst. See *Air Burst.*

SURVEY METER: A portable instrument, such as a Geiger counter or ionization chamber, used to detect nuclear radiation and to measure the exposure rate. See *Monitoring.*

SYNDROME, RADIATION: The complex of symptoms characterizing the disease known as radiation injury, resulting from excessive exposure of the whole (or a large part) of the body to ionizing radiation. The earliest of these symptoms are nausea, vomiting, and diarrhea, which may be followed by loss of hair (epilation), hemmorhage, inflammation of the mouth and throat, and general loss of energy. In severe cases, where the radiation exposure has been relatively large, death may occur within two to four weeks. Those who survive 6 weeks after the receipt of a single exposure of radiation may generally be expected to recover.

T

TAMPER: A strong container.

THERMAL ENERGY: The energy emitted from the fireball as thermal radiation. The total amount of thermal energy received per unit area at a specified distance from a nuclear (or atomic) explosion is generally expressed in terms of calories per square centimeter. See *Thermal Radiation*.

THERMONUCLEAR: An adjective referring to the process (or processes) in which very high temperatures are used to bring about the fusion of light nuclei, such as those of the hydrogen isotopes (deuterium and tritium), with the accompanying liberation of energy. A thermonuclear bomb is a weapon in which part of the explosion energy results from thermonuclear fusion reactions. The high temperatures required are obtained by means of a fission explosion. See *Fusion*.

THERMAL RADIATION: Electromagnetic radiation emitted (in two pulses from an air burst) from the fireball as a consequence of its very high temperature; it consists essentially of ultraviolet, visible, and infrared radiations. In the early stages (first pulse of an air burst), when the temperature of the fireball is extremely high, the ultraviolet radiation predominates; in the second pulse, the temperatures are lower and most of the thermal radiation lies in the visible and infrared regions of the spectrum. From a high-altitude burst, the thermal radiation is emitted in a single short pulse.

TNT EQUIVALENT: A measure of the energy released in the detonation of a nuclear weapon, or in the explosion of a given quantity of fissionable material, expressed in terms of the weight of TNT which would release the same amount of energy when exploded. The TNT equivalent is usually stated in kilotons or megatons. The basis of the TNT equivalence is that the explosion of 1 ton of TNT releases 10^9 calories of energy. See *Kiloton, Megaton, Yield*.

TRANSMUTATION: The changing of one element into another by a nuclear reaction.

TRITIUM: A radioactive isotope of hydrogen, having a mass of 3 units; it is produced in nuclear reactors by the action of neutrons on lithium nuclei.

TROPOPAUSE: The imaginary boundary layer dividing the stratosphere from the lower part of the atmosphere, the troposphere. The tropopause normally occurs at an altiture of about 25,000 to 45,000 feet in polar and temperate zones, and at 55,000 feet in the tropics.

TROPOSPHERE: The region of the atmosphere immediately above the earth's surface and up to the tropopause in which the temperature falls fairly regularly with increasing altitude, clouds form, convection is active, and mixing is continuous and more or less complete.

U

ULTRAVIOLET: Electromagnetic radiation of wave length between the shortest visible violet and soft X-rays.

UNDERGROUND BURST: The explosion of a nuclear weapon with its center more than $5W^{0.3}$ feet, where W is the explosion yield in kilotons, beneath the surface of the ground. See *Contained Underground Burst*.

UNDERWATER BURST: The explosion of a nuclear weapon with its center beneath the surface of the water.

URANIUM: (Chemical symbol U.) The heaviest naturally occurring radioactive element atomic number 92. The only appreciable source of fissionable material occurring in nature is in uranium ore. This contains about 0.7% of the fissionable isotope U^{235} and 99.3% of the nonfissionable isotope U^{238}.

V

(None)

W

WEIGHT: A measure of the force with which matter is attracted to the earth.

WORLDWIDE FALLOUT: See *Fallout*.

X

X-RAYS: Electromagnetic radiations of high energy having wave lengths shorter than those in the ultraviolet region, i.e., less than 10^{-6} cm or 100 Angstroms. As generally produced by X-ray machines, they are bremsstrahlung resulting from the interaction of electrons of 1 kilo-electron volt or more energy with a metallic target. See *Gamma Rays, Electromagnetic Radiation*.

Y

YIELD (OR ENERGY YIELD): The total effective energy released in a nuclear explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion. The total energy yield is manifested as nuclear radiation, thermal radiation, and shock (and blast) energy, the actual distribution being dependent upon the medium in which the explosion occurs (primarily) and also upon the type of weapon and the time after detonation.

Z

(None)

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